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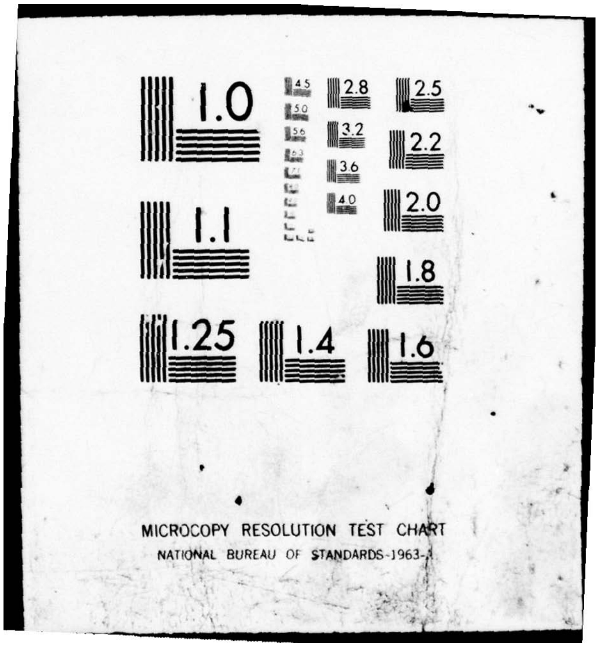
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MISCELLANEOUS PAPER SL-79-7

VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTER PROGRAMS FOR MASS CONCRETE STRUCTURES

by

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March 1979

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, Walla Walla
Walla Walla, Wash. 99362

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) WES-MP- Miscellaneous Paper SL-79-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTER PROGRAMS FOR MASS CONCRETE STRUCTURES.		5. TYPE OF REPORT & PERIOD COVERED (9) Final Report.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Tony C. Liu, Roy L. Campbell, Anthony A. Bombich		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer Waterways Experiment Station Structures Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Engineer District, Walla Walla Walla Walla, Wash. 99362		12. REPORT DATE (11) March 1979
		13. NUMBER OF PAGES 106
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 111 p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer programs
Concrete dams
Concrete structures
Dworshak Dam
Mass concrete
Temperature
Thermal stresses

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this investigation was to validate the accuracy and effectiveness of the temperature and thermal stress/strain calculation programs currently being used by the Corps of Engineers by comparing analytical results with measured data obtained from embedded gages in Dworshak Dam.

History of construction, weather data, and available material properties of Dworshak Dam were used for computer program input.

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20. ABSTRACT (Continued).

Cont

Based on the results of this investigation, it can be concluded that the temperature and thermal stress calculation programs currently being used by the Corps are acceptable. Recommendations for further improvement of these computer programs are presented.

PREFACE

The work reported herein was conducted for the U. S. Army Engineer District, Walla Walla (NPW), by the Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES). Authorization for this investigation was given in DA Form 2544, dated 15 March 1978.

The material property information, construction history, instrumentation data, and the Walla Walla version of the temperature-calculation program used in this investigation were provided to WES by NPW and North Pacific Division Laboratory.

This investigation was performed under the direction of Messrs. B. Mather, J. M. Scanlon, and J. E. McDonald, SL. Dr. Tony C. Liu, Messrs. R. L. Campbell, and A. A. Bombich prepared this report.

The Commander and Director of WES during the conduct of this investigation and the preparation and publication of this report was COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiple	By	To Obtain
Btu · inch per hour · square inch · degree F	20.7688176	watts per metre · Kelvin
Btu per hour · square foot · degree Fahrenheit	5.678263	watts per square metre · Kelvin
Btu per pound (mass) · degree Fahrenheit	4186.8	joules per kilogram · Kelvin
calories per gram	4.184	kilojoules per kilogram
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
inches	0.0254	metres
inches per degree Fahrenheit	0.014111111	metres per Kelvin
pounds (force) per square inch per minute	114.91267	pascals per second
pounds (force) per square inch (psi)	6894.757	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds per cubic yard	0.5932764	kilograms per cubic metre
square feet per hour	0.0000258064	square metres per second

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = C + 273.15$.

VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTER PROGRAMS FOR MASS CONCRETE STRUCTURES

PART I: INTRODUCTION

Background

1. Currently, two finite element computer programs are being used by the Corps to predict temperature distribution and resulting thermal stresses and strains in mass concrete structures. The first program,[1] developed by Dr. E. L. Wilson of the University of California (UC) at Berkeley, calculates temperatures within a mass concrete structure. The second program,[2] written by Dr. R. S. Sandhu, et al., also at UC Berkeley, calculates the thermal stresses and strains within the structure involving incremental construction and creep. These two computer programs are considered to be the most effective numerical methods for calculating temperature and thermal stresses/strains in the mass concrete structures. Because they are not only completely general with respect to geometry, material properties, and boundary conditions, but also provide the capability of simulating incremental construction and creep of mass concrete structures, these programs have been used for concrete temperature control studies for several Corps mass concrete structures, including Dworshak Dam. However, these programs have never been verified with actual field measured data.

2. As in many other dams, stress and strain meters, thermocouples, and other instruments were embedded in Dworshak Dam during construction to give information on structural behavior. Measurements have been obtained from these instruments since the beginning of construction in 1968. These measured data, together with the available laboratory information on concrete thermal and mechanical properties, provide a unique opportunity for verifying the computer programs.

Purpose and Scope

3. The purpose of this investigation was to verify the temperature and thermal stress/strain computer programs by comparing the analytical results with the measured data obtained from the embedded gages in the Dworshak Dam.

4. Because of the funding and time limitations, the analysis of the complete dam, taking full account of the time-varying thermal, elastic, and creep properties of concrete, was not considered possible. It was decided that the objective of this investigation could be achieved by analysis of the lower region of the Monolith 23, including foundation and 14 concrete lifts, during the period between 26 August 1968 and 15 February 1969.

5. History of construction, weather data, and available material properties of Dworshak Dam were used for computer program input. Calculated temperatures and stress/strain history were compared with the measured data. The validity and reliability of the computer programs are discussed, and recommendations for further development of temperature and thermal stress calculation programs are presented.

PART II: FINITE ELEMENT COMPUTER PROGRAMS

Temperature-Calculation Program

6. This program, developed by Dr. Wilson, calculates the temperature distribution as a function of time within a concrete structure as it is being constructed. Each lift of the structure may be placed at an arbitrary time and temperature. Insulating forms may be placed or removed from the surfaces. The external air temperature and temperature of the cooling water may also vary with time. The finite element technique coupled with a step-by-step time integration procedure is used as the method of analysis. Detailed discussion of this computer program is given in Reference 1.

7. Some input and output formats of Dr. Wilson's program were modified at WES for the convenience of the users. Both the WES and Walla Walla versions of the temperature-calculation program were used in this investigation and, as expected, the results were found to be identical. The WES version of temperature program is given in Appendix A.

Thermal Stress/Strain Calculation Program

8. This program, developed by Dr. Sandhu, calculates the displacements at each node and the strains and stresses developed in each element in the finite element model due to thermal, gravity, and other external loads. In allowing for creep, this program assumes that relaxation of stress takes place without nodal displacements over a small time increment during which the material properties do not change. This change in stress is then neutralized by releasing the constraints and treating the stress changes as residual stresses. Detailed discussion of this program is given in Reference 2.

9. In Dr. Sandhu's original program,[2] only one arbitrary reference temperature (stress-free temperature) was specified for all elements. The stress-free temperature input was modified in the WES version of the thermal stress program in which the stress-free temperature for an element is defined as the temperature at 8 hr after placement.

The stress-free temperatures for all elements are calculated in the WES version of the temperature calculation program and stored on disc file for subsequent input to the thermal stress analysis.

10. The WES version of the thermal stress analysis program was used in this investigacion (Appendix B).

PART III: DETERMINATION OF CONCRETE TEMPERATURES

Finite Element Model

11. The finite element model selected for this investigation is representative of a small interior portion of Monolith 23. Figure 1 shows the typical cross section of Monolith 23 and Figure 2, the typical cooling pipe arrangement. Due to considerations of symmetry, only a 30-in.* wide slice was analyzed as shown in Figure 2.

12. The height of the finite element model was 80 ft (from El 930 to El 1010), representing 10 ft of foundation and 14 lifts of concrete at 5 ft per each lift. The plan of the model was located at 330 ft from the construction base line and center of the monolith. The finite element model, consisting of 576 nodes and 475 elements, is shown in Figure 3.

13. Except for the top concrete surfaces, all boundary conditions were assumed to be adiabatic because negligible boundary heat flow was expected in the interior portion of a mass concrete structure.

Material Types

14. Four adjustments in fly ash and cement contents in the concrete mixtures were made between August and December of 1968. Variations in concrete mixtures would affect the thermal and mechanical properties of concrete. Therefore, five material types (one foundation material and four concrete materials) were used in the analysis. A summary of material types used is given in Table 1.

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* A table of factors for converting U.S. customary units of measurement to metric (SI) units is given on page 3.

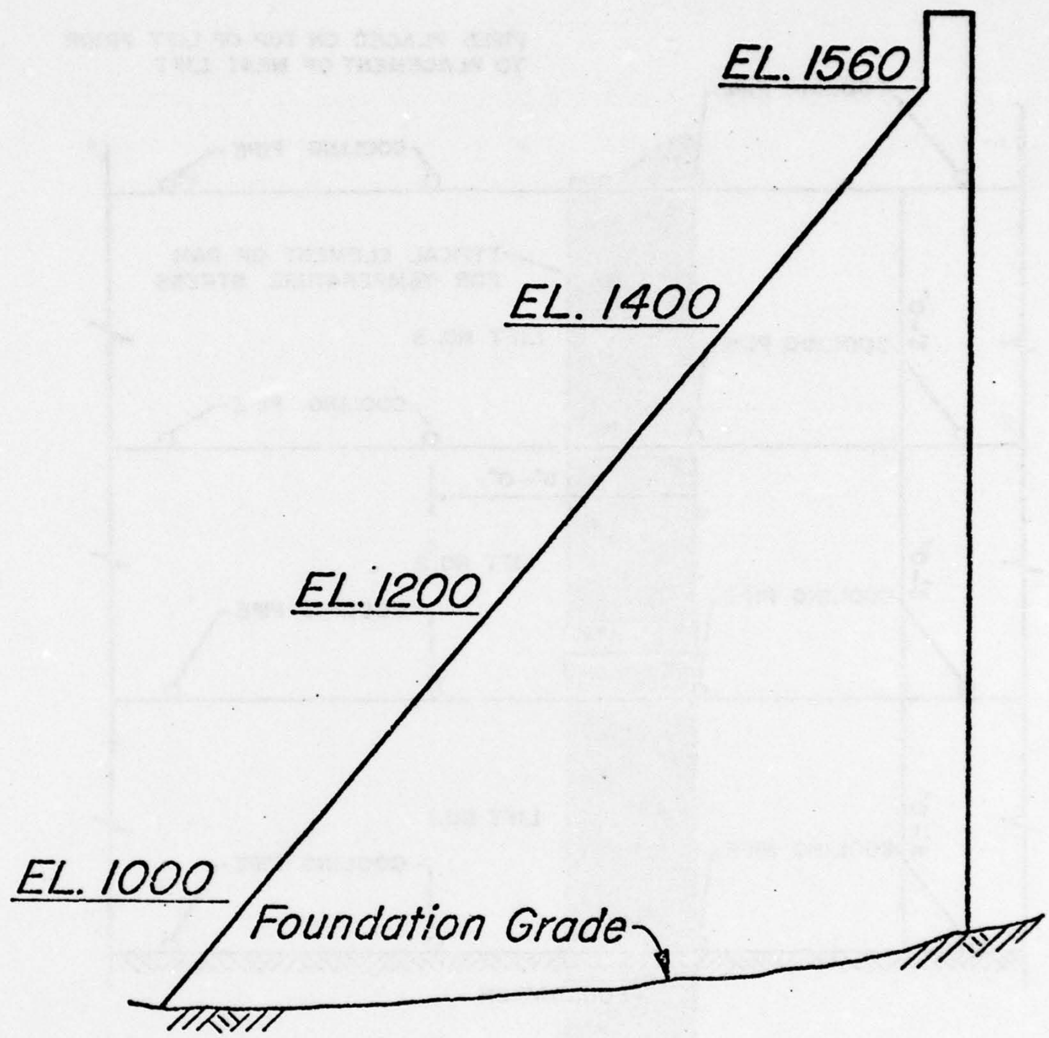

Figure 1. Cross Section of Monolith 23

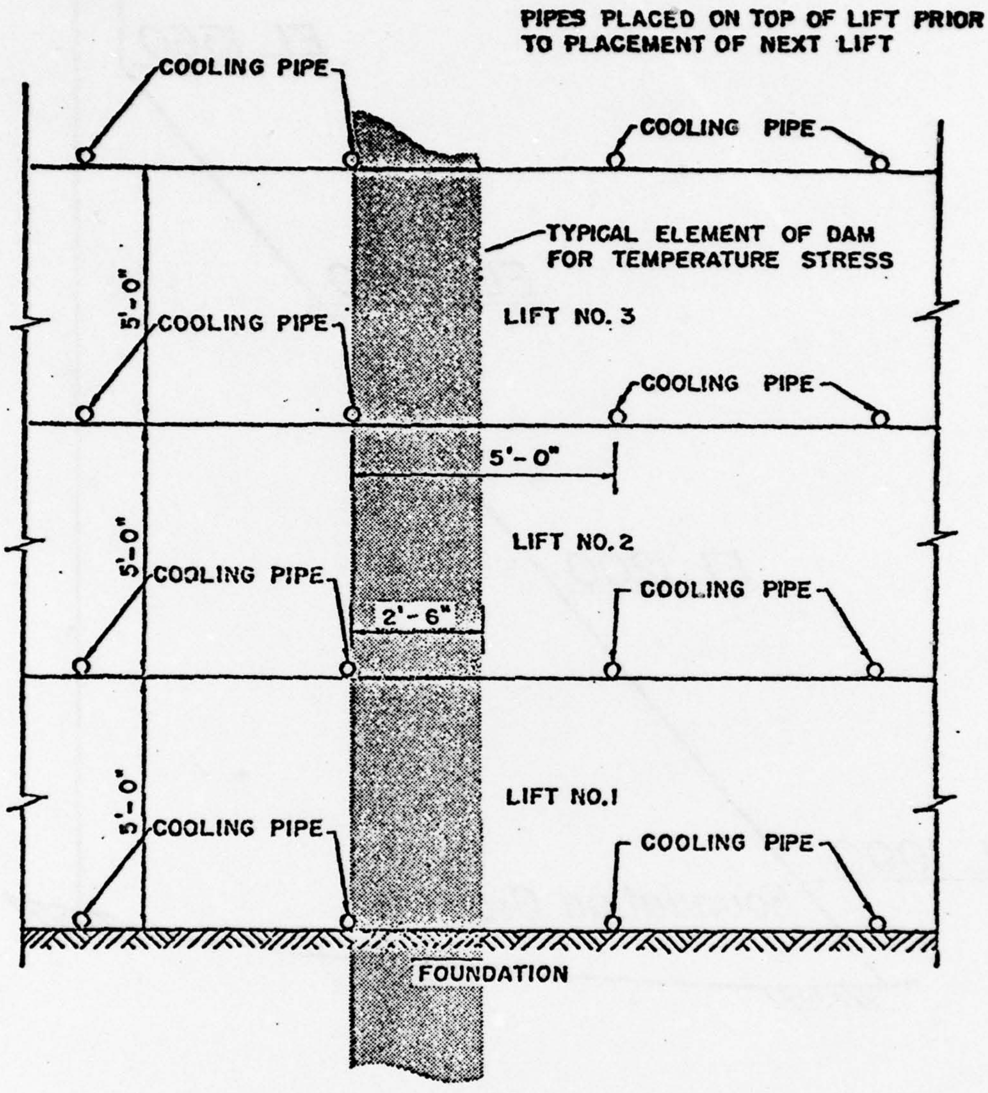

Figure 2. Typical Arrangement of Cooling Pipes

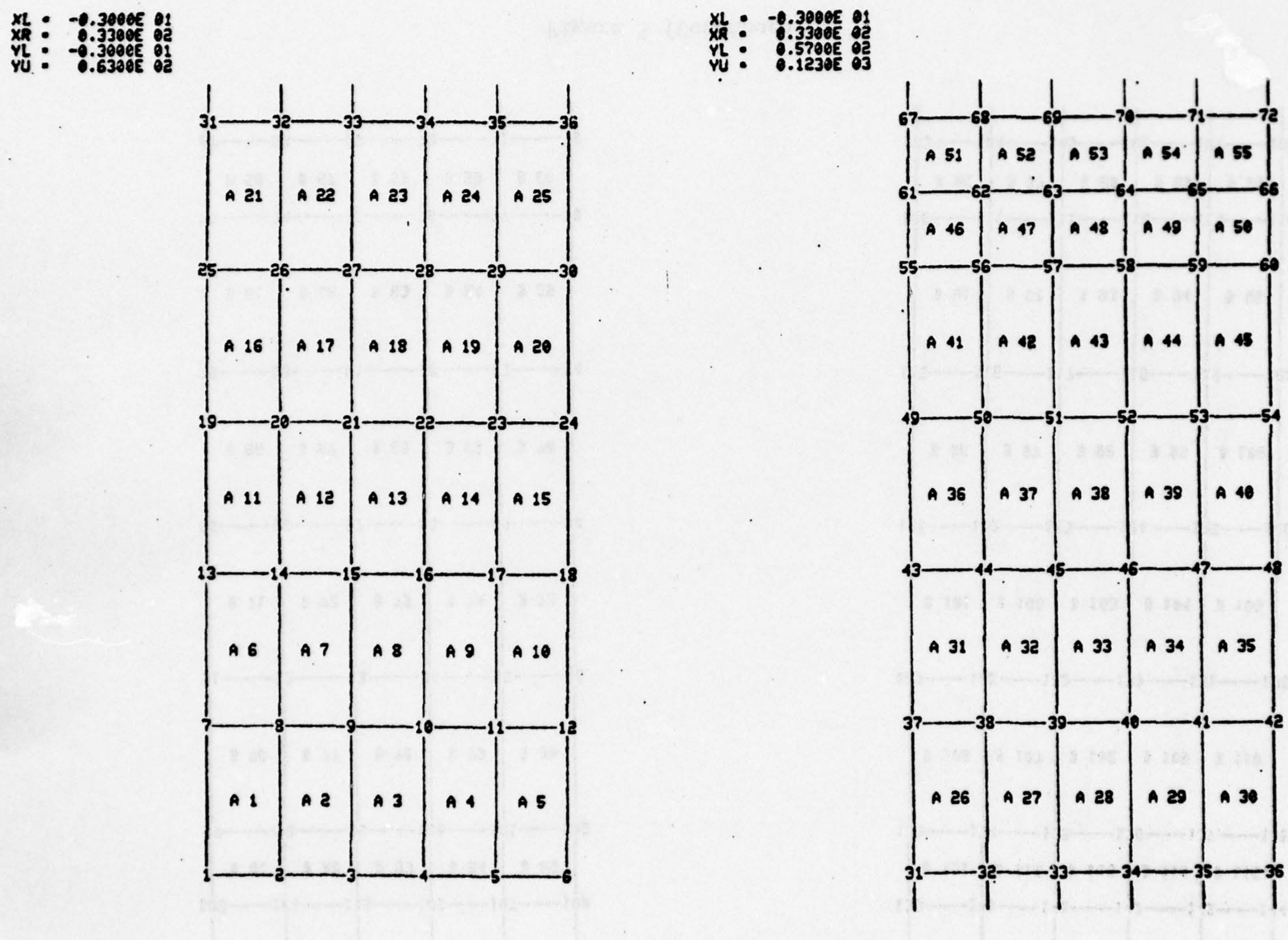

Figure 3. Finite Element Model

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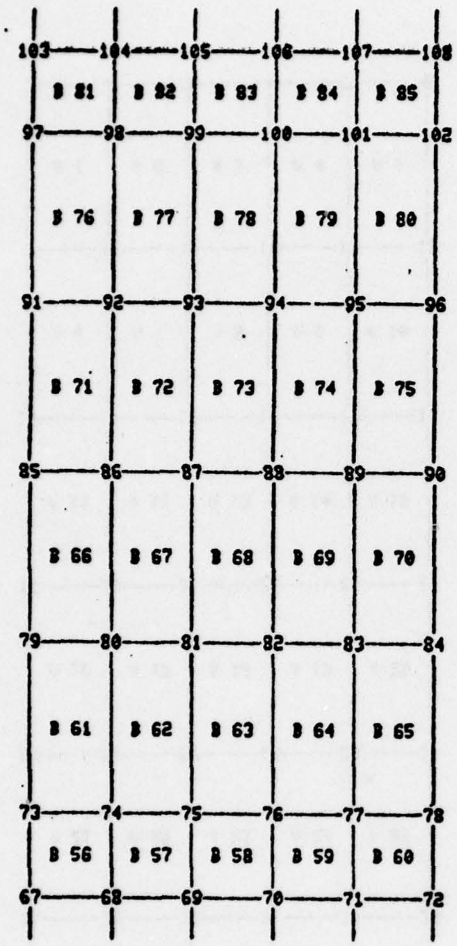

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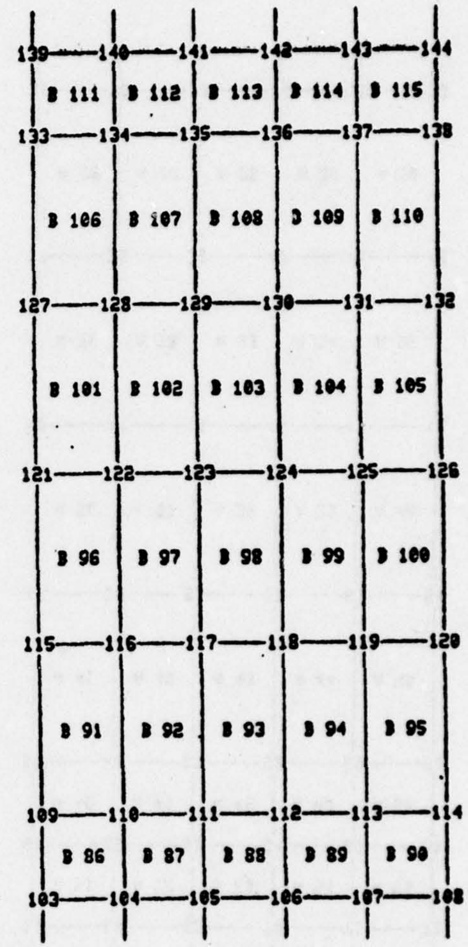

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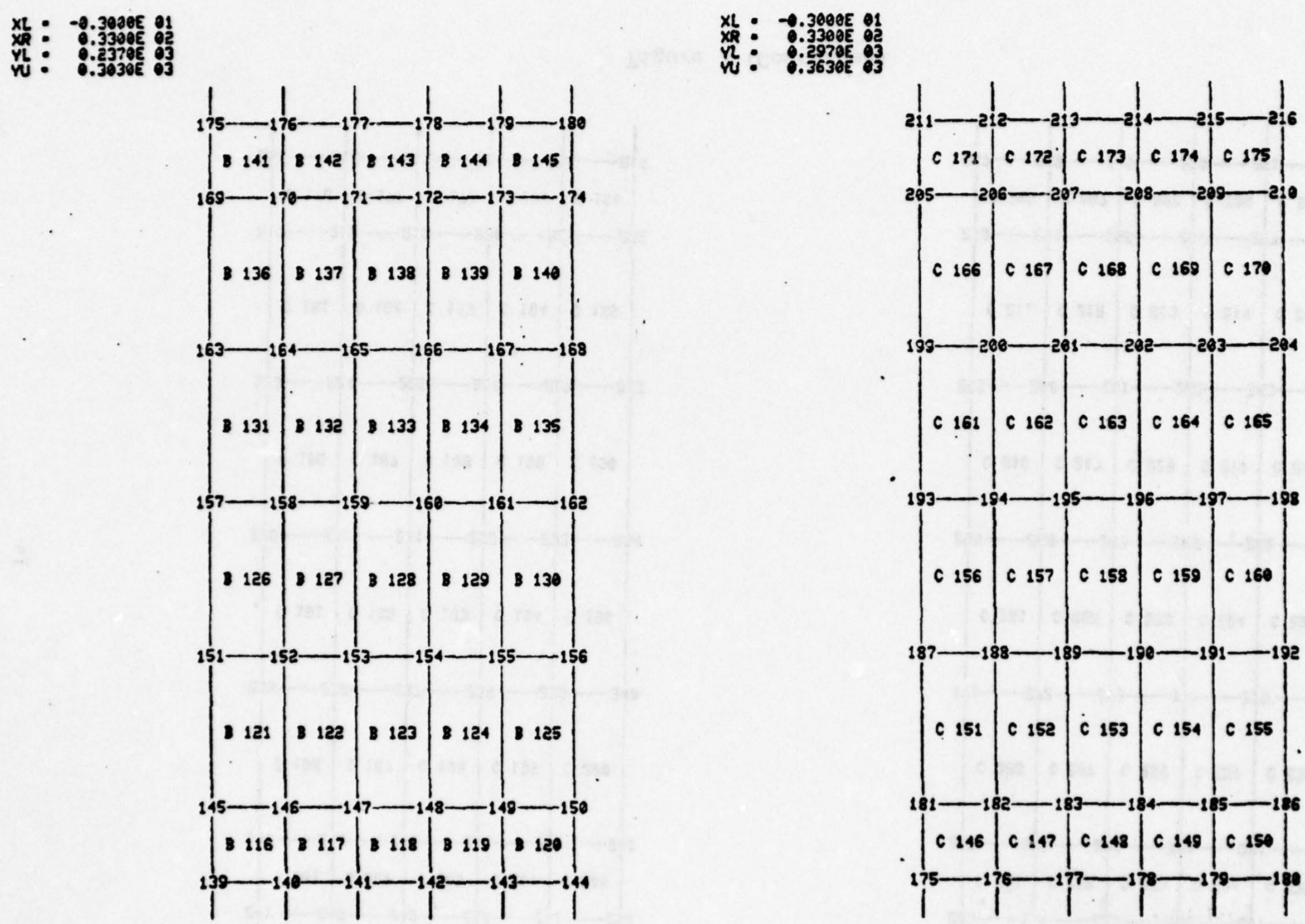

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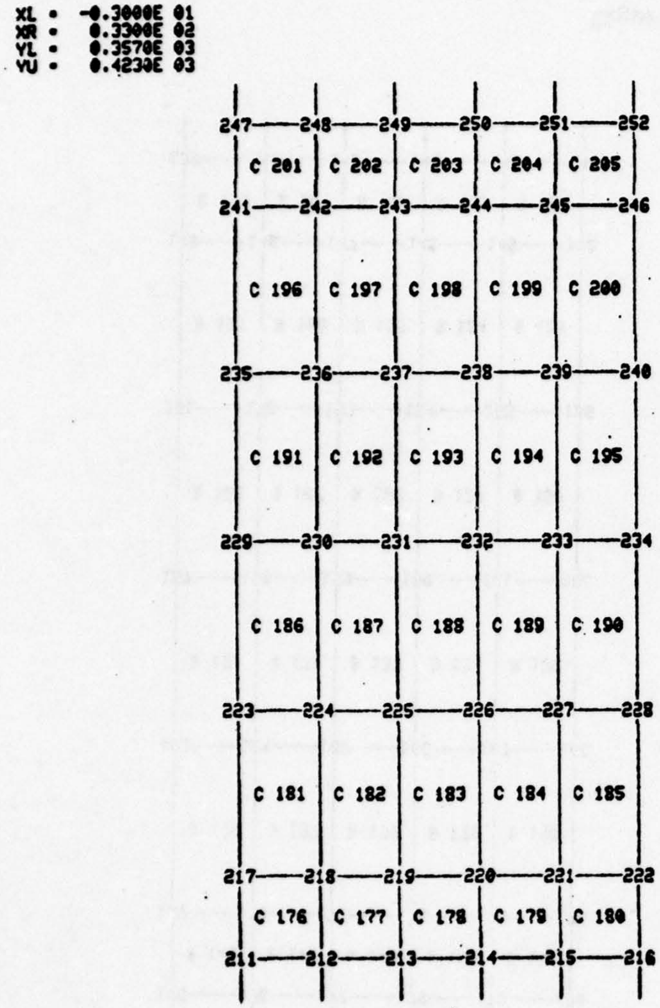

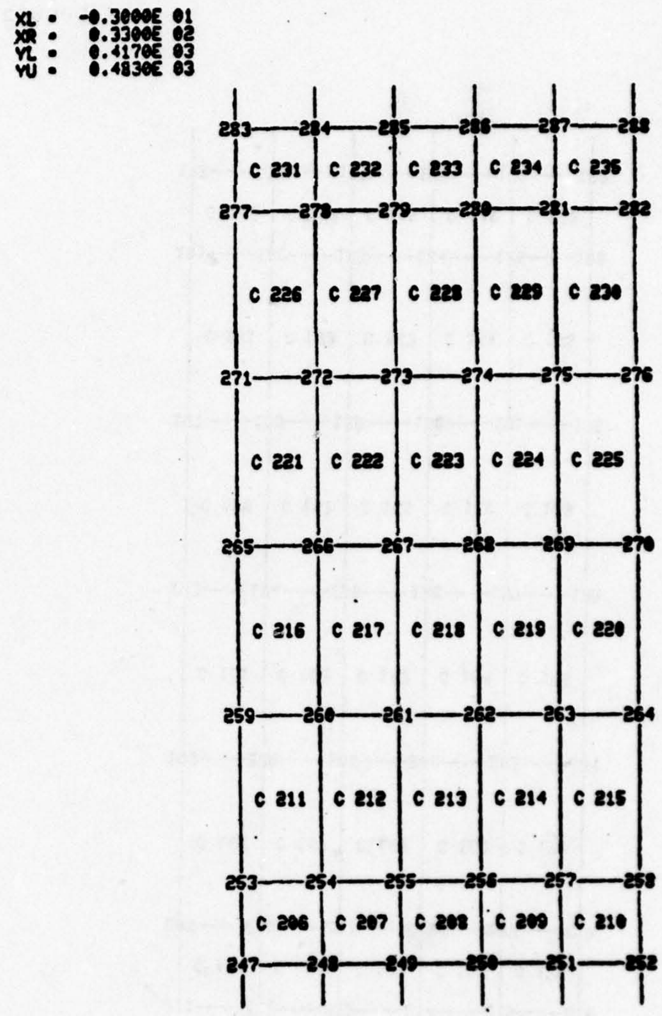

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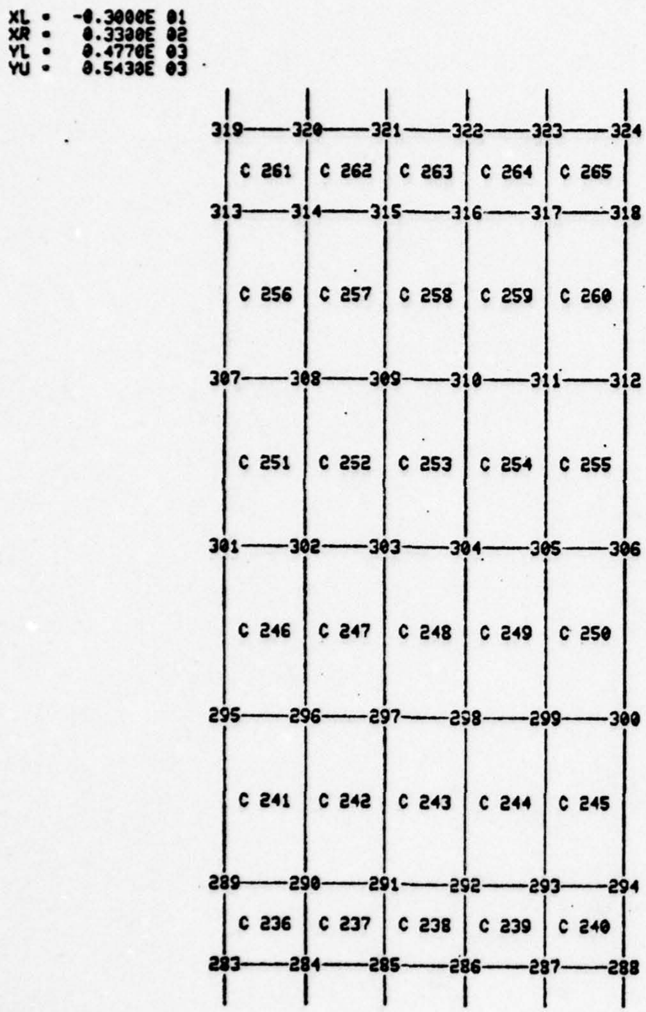

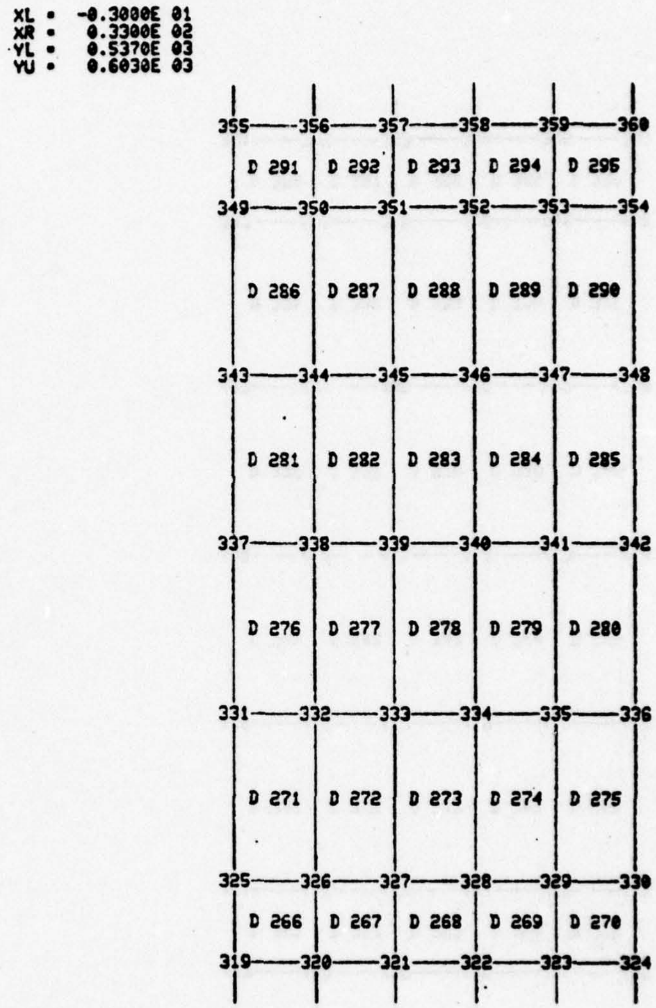

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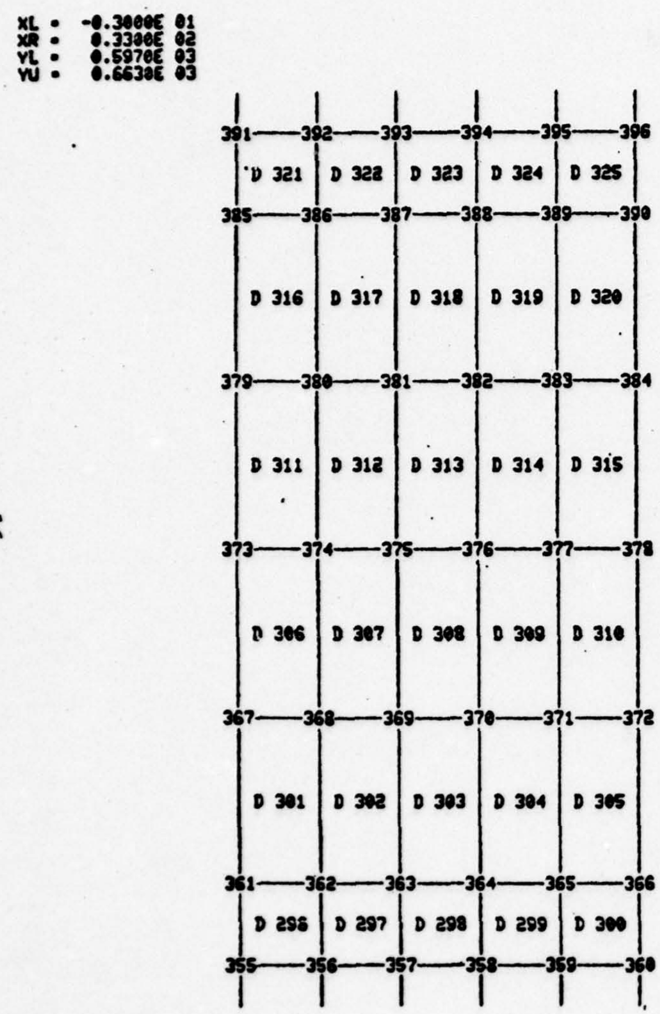

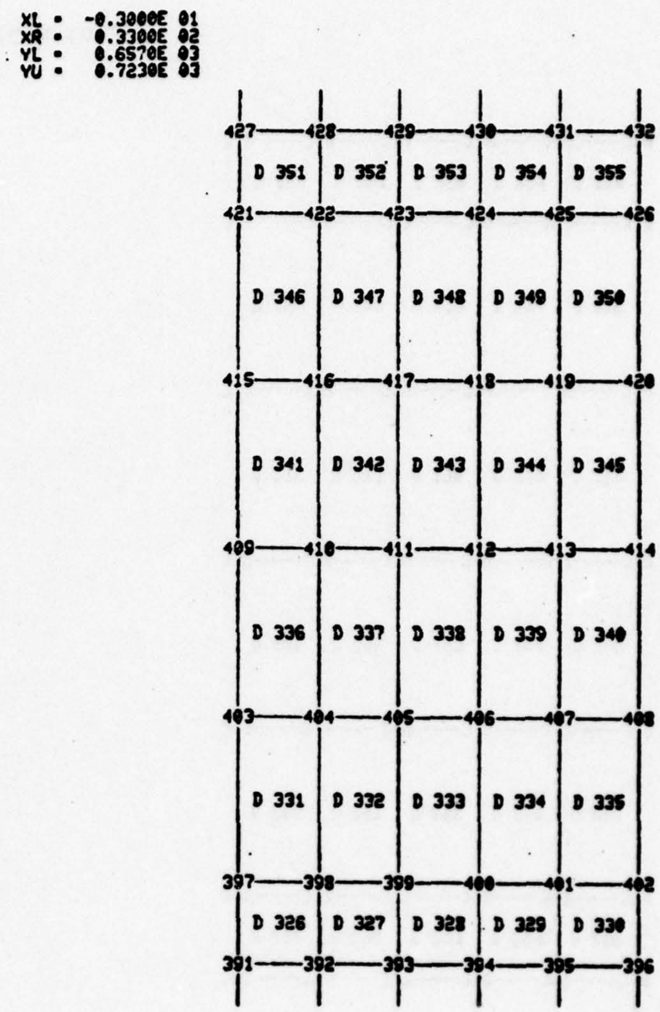

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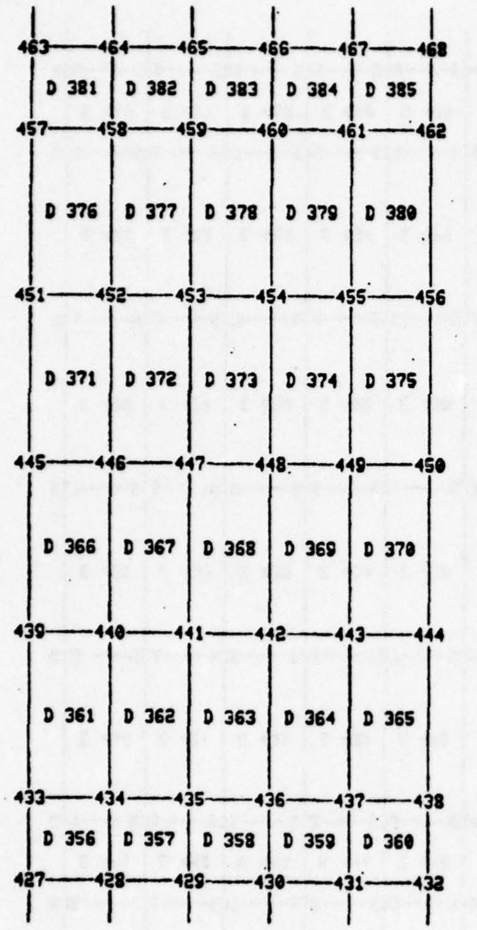

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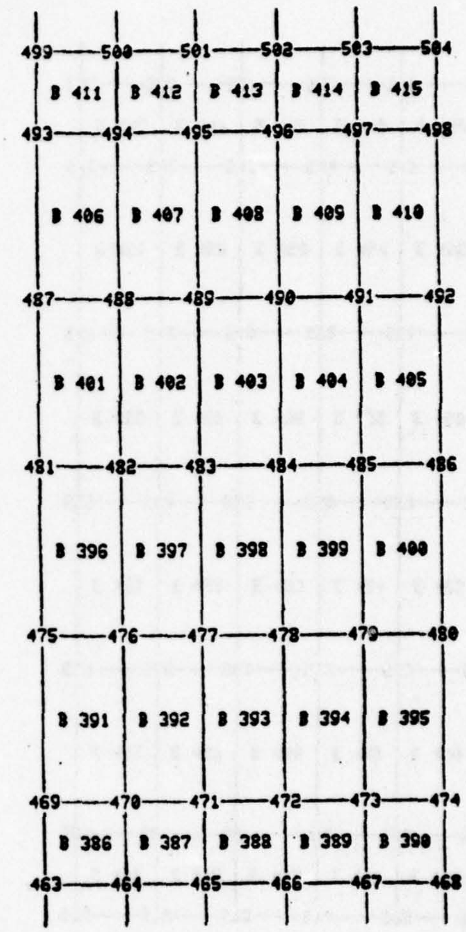

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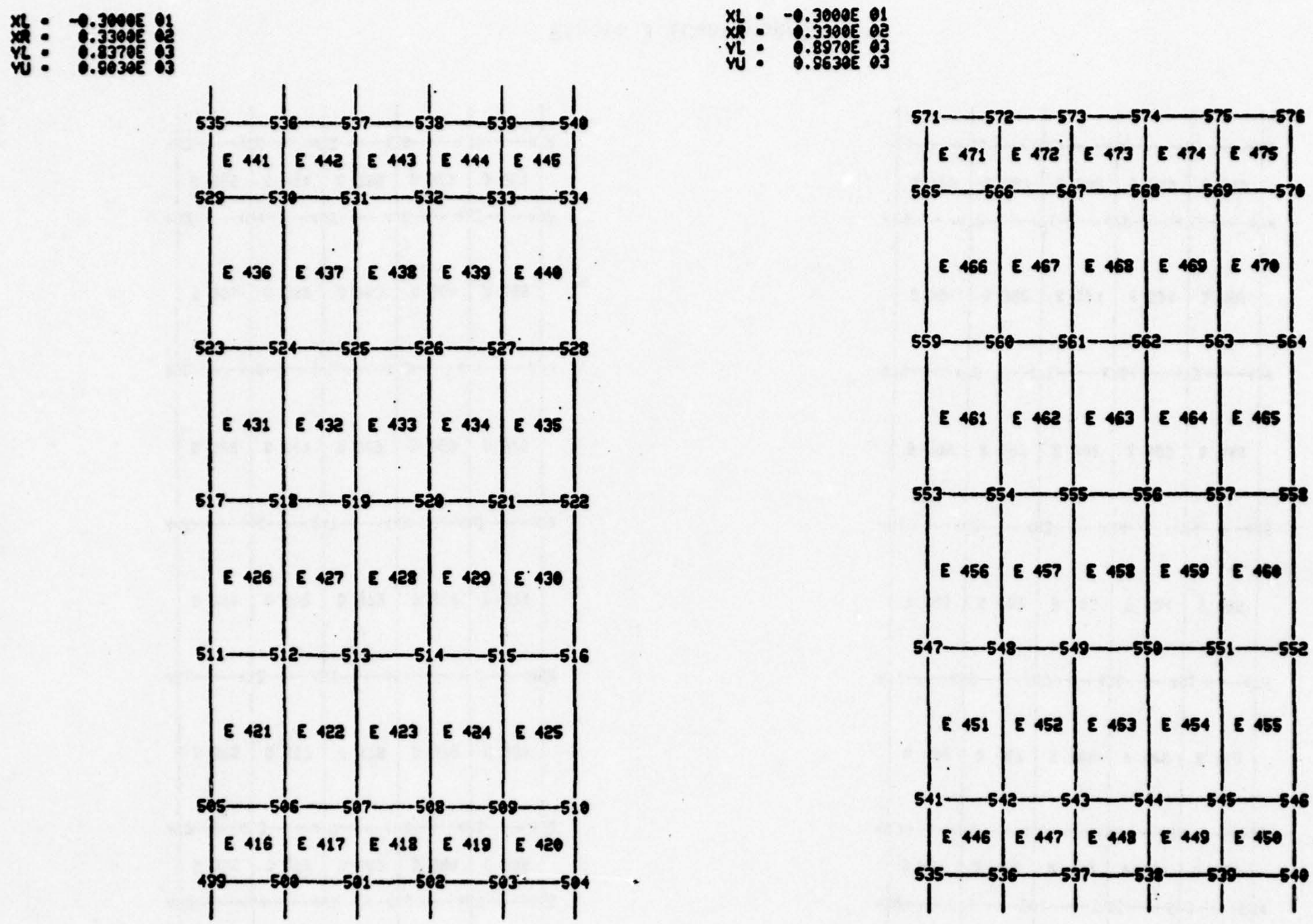

Figure 3 (Concluded)

Thermal Properties of Concrete and Foundation

15. The thermal properties of concrete and foundation required by the temperature calculation program are (a) specific heat, (b) density, (c) thermal conductivity, and (d) adiabatic temperature rise versus age. The values of thermal properties used in the analysis are given in Tables 2 and 3.

16. The specific heat, density, and thermal conductivity of material Type 2 were obtained from the test results of mixture No. A-2 reported in Appendix C of Reference 4. The thermal properties of other concrete material types used in the analysis were interpolated from the available test data given in Reference 4. The thermal properties of foundation material (material Type 1) were assumed to be identical to material Type 2.

17. The adiabatic temperature rise data presented in Table 3 were derived from the test results given in page 2.3-9 of Reference 4. The adiabatic temperature rise data beyond 28 days were obtained by extrapolation of the available data on a semi-logarithmic plot.

Construction Parameters

Ambient temperatures

18. The mean daily ambient temperature at Dworshak Dam from 26 August 1968 to 15 February 1969, during which the construction is being simulated, is plotted in Figure 4. This information was provided by the Walla Walla District. The simplified ambient exposure temperatures used in the analysis are shown in Figure 5.

Foundation temperature

19. In order to simulate the foundation temperatures in the model, the temperature of the entire foundation was first set equal to $65^{o}F$. It was assumed that the temperature at the bottom of the foundation would remain constant throughout the analysis period. Prior to the beginning of construction simulation, the surface of the foundation was exposed to

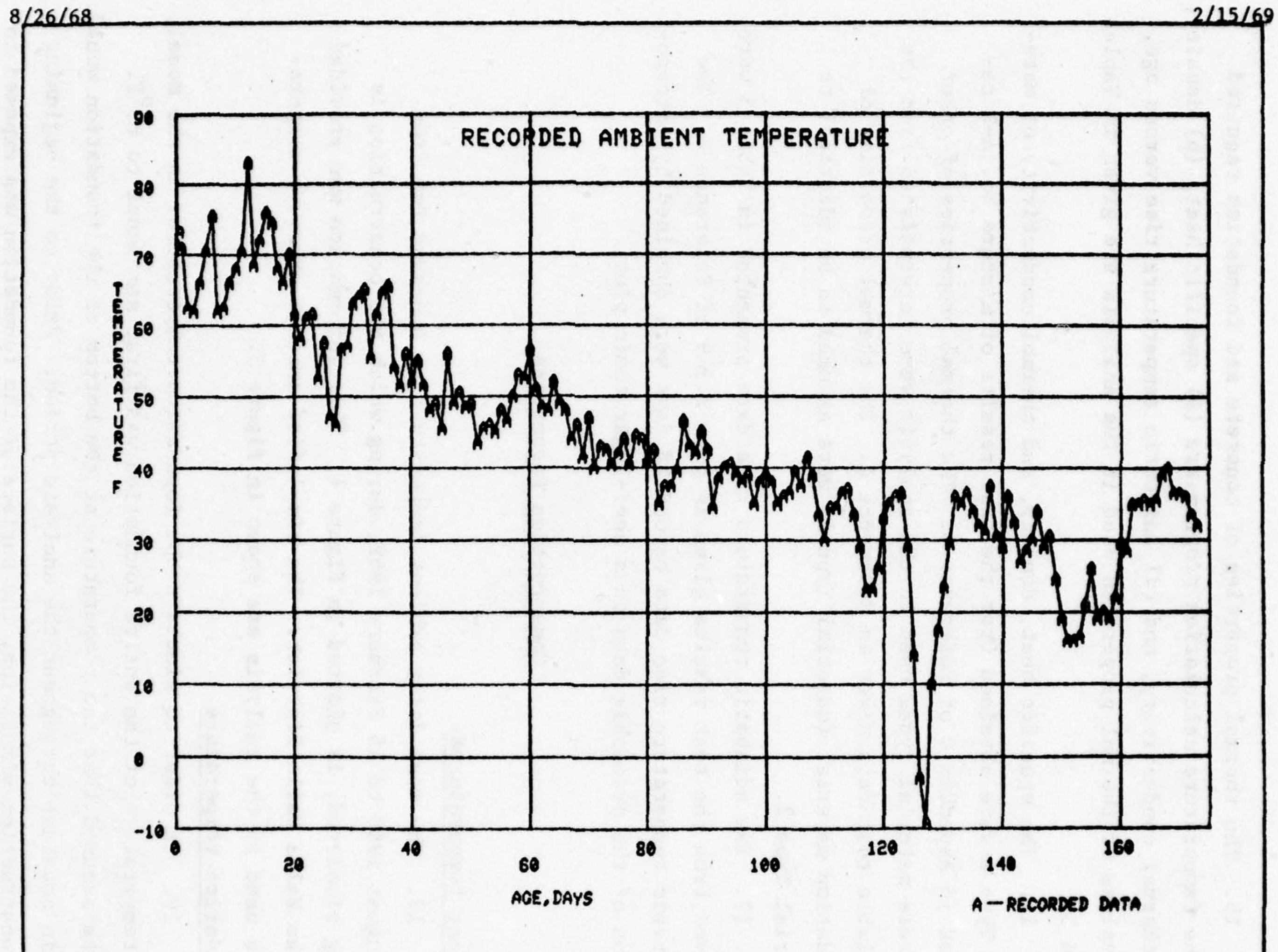

Figure 4. Mean Daily Ambient Temperatures, Dworshak Dam

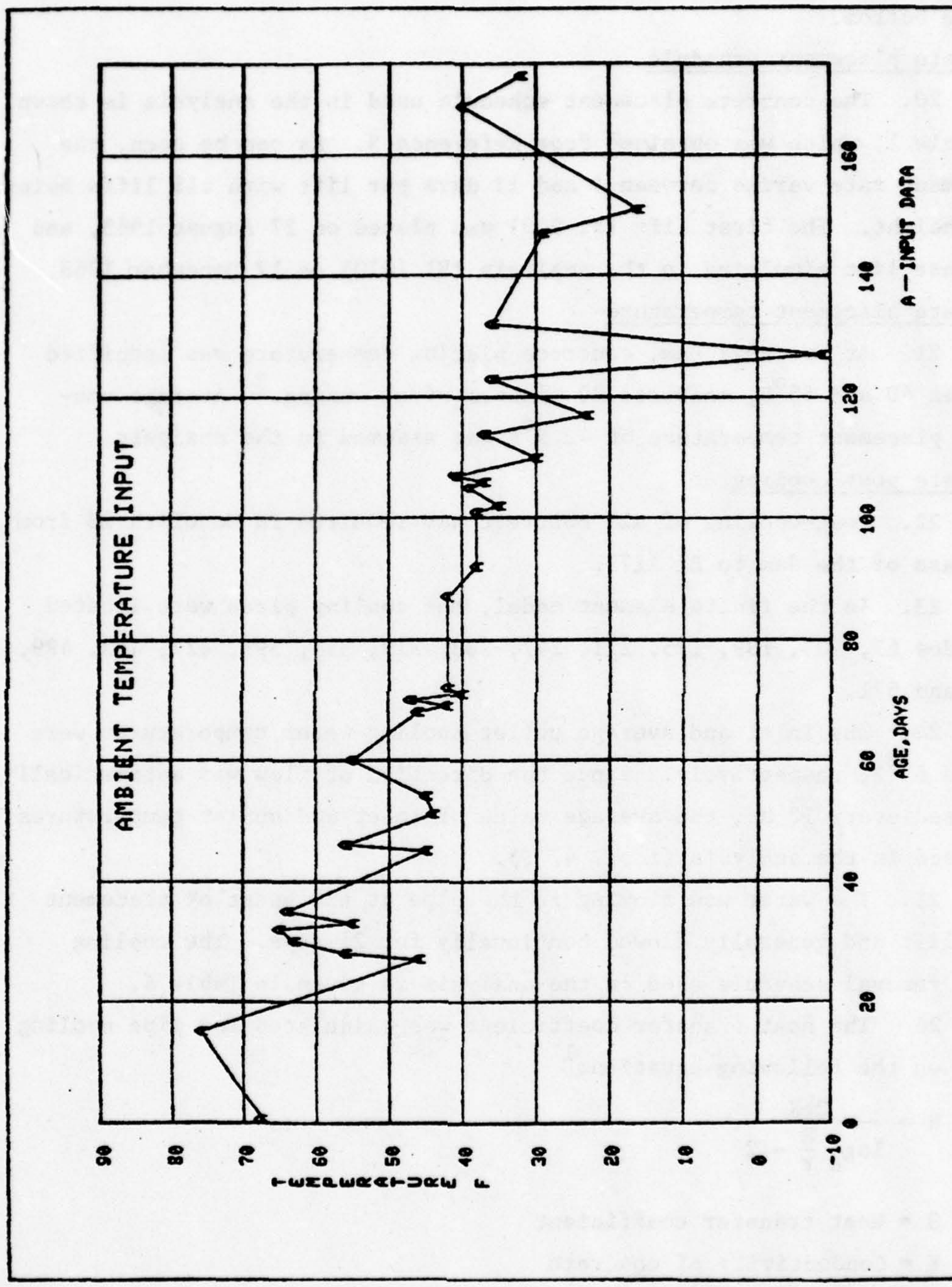

Figure 5 Ambient Temperatures Used in the Analysis

ambient temperature and calculation was made to equilibrate foundation temperatures between ambient at the surface and the constant temperature at the bottom.

Concrete placement schedule

20. The concrete placement schedule used in the analysis is shown in Table 1, which was obtained from Reference 3. As can be seen, the placement rate varied between 4 and 13 days per lift with all lifts being 5-ft height. The first lift (El 940) was placed on 27 August 1968, and the last lift simulated in the analysis (El 1010) on 17 December 1968.

Concrete placement temperature

21. At Dworshak Dam, concrete placing temperature was specified between 40 and 45°F, measured 20 minutes after mixing.[3] Average concrete placement temperature of 42.5°F was assumed in the analysis.

Concrete post-cooling

22. Post-cooling of all concrete was required in Monolith 23 from the base of the dam to El 1175.

23. In the finite element model, the cooling pipes were located at nodes 67, 103, 139, 175, 211, 247, 283, 319, 355, 391, 427, 463, 499, 535, and 571.

24. The inlet and average outlet cooling water temperatures were 41 and 53°F, respectively. Since the direction of flow was automatically reversed every 12 hr, the average value of inlet and outlet temperatures was used in the analysis (i.e., 47°F).

25. The water was flowing in the pipe at the start of placement in a lift and generally flowed continually for 21 days. The cooling water removal schedule used in the analysis is given in Table 4.

26. The heat transfer coefficient was calculated for pipe cooling based on the following equation:[1]

$$H = \frac{2\pi K}{\log_e \frac{R}{r} - 2}$$

where H = Heat transfer coefficient

K = Conductivity of concrete
= 0.113 Btu/hr-in.-°F

R = Mesh size in the vicinity of the pipe
= 6 in.

r = Radius of cooling pipe
= 0.5 in.

Because of symmetry at the cooling pipes, the mathematical model (Figure 2) included only concrete elements from the pipe location to a distance half-way to the next cooling pipe. Therefore, half of the calculated H value was used in the program calculations.

Surface insulation

27. During construction, the top lift surface was generally covered with insulating mats immediately after placing. The insulation remained in place until the lift surface was to be covered with concrete, except for the time during which the joint was cleaned with high-pressure water jet.

28. The thermal conductivities of insulation materials used in the analysis are shown in Table 5.[3]

Wind velocities

29. In order to compute the convection transfer coefficient, wind velocity data are required. The wind data used in the analysis were obtained from Dworshak Station and are summarized in Table 6.

Heat transfer coefficients

30. The surface heat transfer coefficients used in the analysis were calculated according to the following equation;[1]

$$H = \frac{1}{\frac{1}{c} + \frac{1}{h'}}$$

where H = Heat tranfer coefficient

c = Conductance of insulation

h'= Convection transfer coefficient
= $0.99 + 0.21V$ for $V < 16$ fps*

V = wind velocity

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* From ASHRAE Handbook, 1977 Fundamentals.

31. Based on the data given in Tables 5 and 6, the surface heat transfer coefficients used in the analysis are summarized in Table 7.

Results and Discussion

32. The analysis was performed for 174 days, from 26 August 1968 to 15 February 1969. Calculated temperatures were output at one-day intervals for all nodes in the model at the particular stage of construction.

33. In general, peak temperatures of approximately 66°F were attained after about five days. Placing of precooled overlying lifts resulted in lower temperatures subsequent to their placement. After attainment of peak temperature, the temperature of a lift dropped as long as cooling was continued. When cooling of a lift was stopped at 21 days but continued on the overlying lifts, the temperature rose gradually to approximately the primary peak at about 40 days, and this temperature remained essentially constant throughout the remaining analytical period. The comparisons between calculated and measured temperatures are made at nodes 198, 342, and 486, where thermocouples 2309B, 2319B, and 2329B, respectively, are located. As can be seen from Figures 6, 7, and 8, excellent agreements between calculated and measured temperatures are obtained. The average differences between calculated and measured temperatures were 0.80°F, 1.56°F, and 1.57°F for nodes 198, 342, and 486, respectively. These small discrepancies were due probably to the following reasons.

- a. The adiabatic temperature rise data used in the analysis were based on the 28-day test results. It is obvious that heat is still being generated for an extended period of time after the 28-day adiabatic temperature rise test period. The adiabatic temperature rise data beyond 28 days were assumed in the analysis because this information was not available.
- b. Average concrete placement temperature of 42.5°F was assumed in the analysis. No record of actual concrete temperatures at placement was available.
- c. The average cooling water temperature was used in the analysis because the actual inlet and outlet cooling water temperatures were not available.

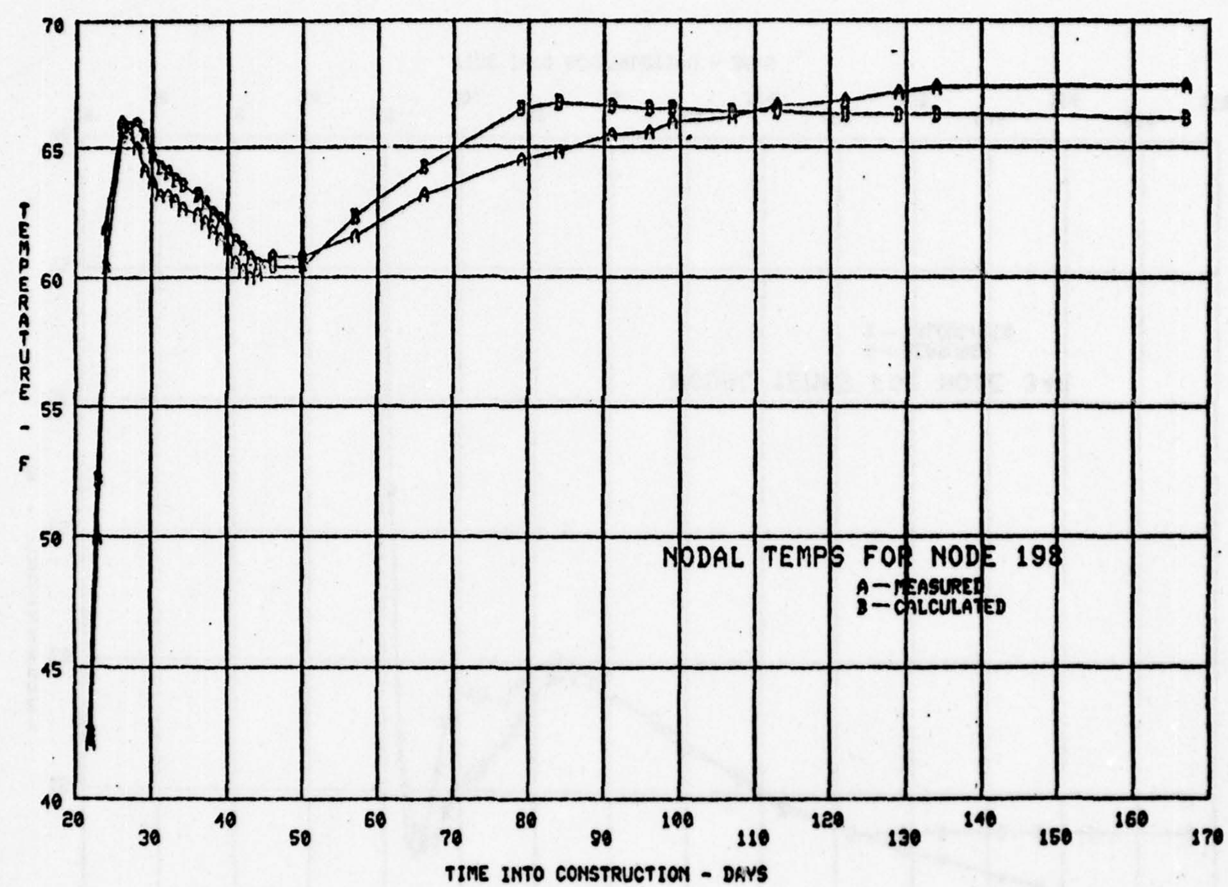

Figure 6. Comparison Between Calculated and Measured Temperatures at Node 198

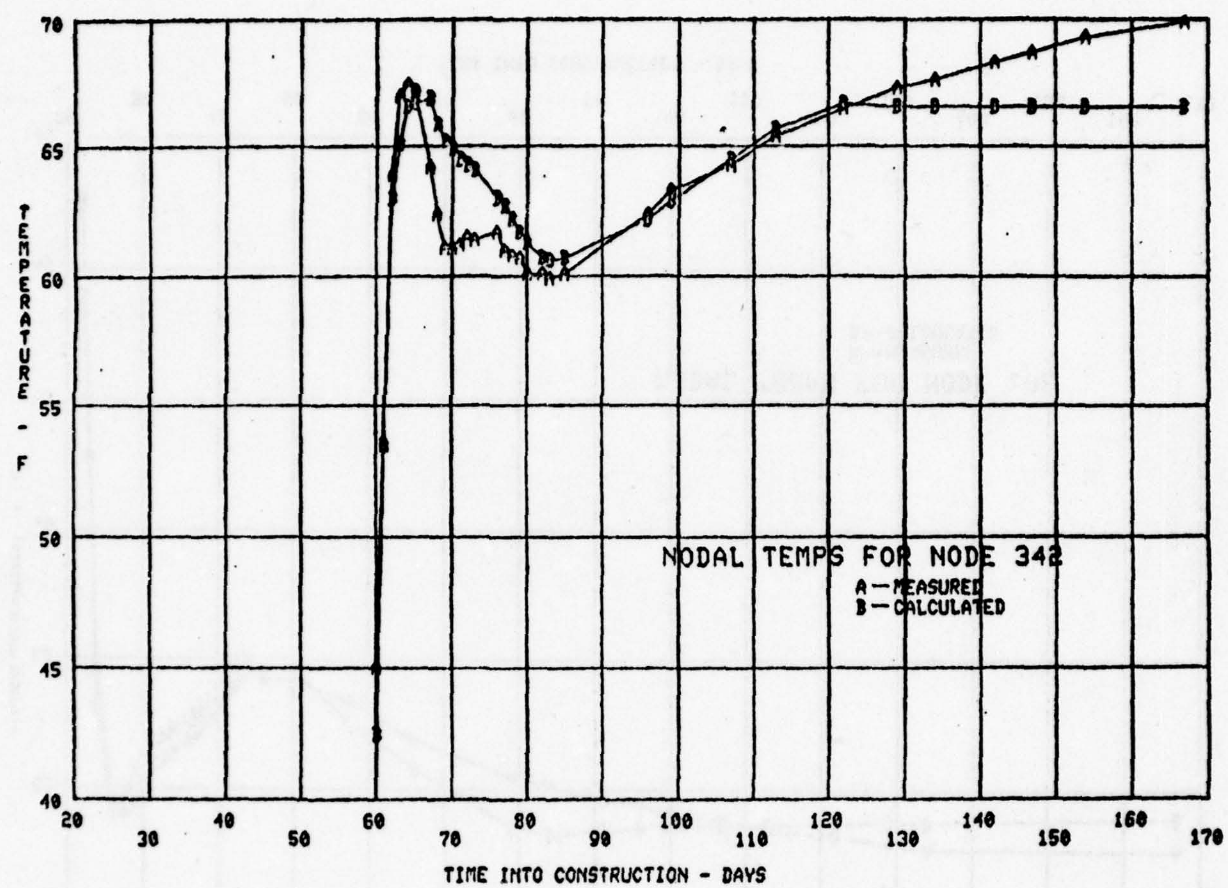

Figure 7. Comparison Between Calculated and Measured Temperatures at Node 342

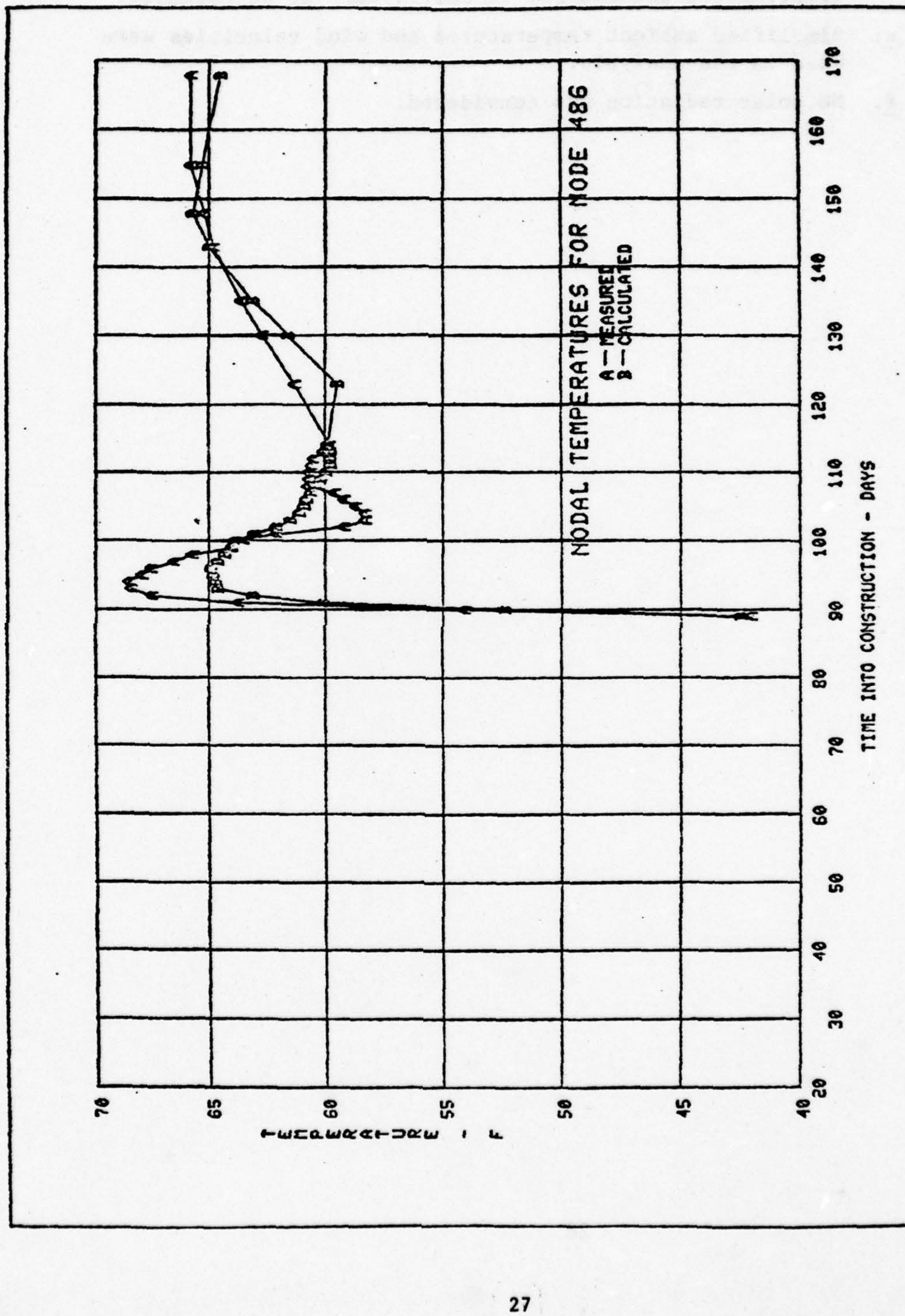

Figure 8. Comparison Between Calculated and Measured Temperatures at Node 486

d. The thermocouple 2319B clearly indicated that the concrete cooling rate was too rapid at node 342 , and the water flow was interrupted between Day 70 and Day 75 (Figure 7). In the analysis, however, only the specified cooling flow was used. Discrepancies between measured and calculated temperatures between Day 70 and 75 were to be expected.

e. Simplified ambient temperatures and wind velocities were used in the analysis.

f. No solar radiation was considered.

PART IV: DETERMINATION OF THERMAL STRESSES

Finite Element Model

34. The same finite element model used in the temperature calculation program was used. Because of symmetry, no horizontal displacement at the vertical boundary was permitted and shear force was assumed to be zero. The nodal points at the bottom of the foundation were assumed fixed in all directions.

Properties of Concrete and Foundation

35. The properties of concrete and foundation required for the thermal stress analysis are (a) modulus of elasticity versus age, (b) Poisson's ratio versus age, (c) coefficient of thermal expansion, (d) shear foundation factor, and (e) creep versus age.

36. The values of modulus of elasticity, Poisson's ratio, and coefficient of thermal expansion are given in Tables 8 through 12. These values were derived from limited test data reported in Reference 4. All shear foundation factors are assumed to be zero.

37. The mathematical formulation of the creep mechanism used in the computer program was proposed originally by McHenry.[5] It may be expressed as follows:

$$\varepsilon_c(t) = \sigma \sum_{i=1}^{u} a_i(T)\{1 - e^{-m_i(t-T)}\}$$

where $\varepsilon_c(t)$ = Creep strain

σ = Applied stress

t = Time after placement

T = Age at loading

$m_i, a_i(t)$ = Creep constants

38. McHenry suggested that a sufficient number of terms be included in this series to give satisfactory agreement with available experiment data. In the present study, it was assumed that two terms would

suffice. The function of $a_1(T)$ and $a_2(T)$ used in the analysis are given in Table 13. The values of m_1 and m_2 were 0.034 and 0.52, respectively. These creep constants were derived based on the results of the creep tests performed at UC Berkeley[6] as reported in Reference 4.

Analysis Time Interval

39. In the analysis, the stress relaxation of the concrete within the finite elements was carried out by a time-increment sequence. Thus, it was necessary to establish time intervals short enough to give the desired accuracy but long enough to retain computational efficiency.

40. A total of 90 analysis times covering 26 August 1968 through 15 February 1969 was selected for the analysis.

Results and Discussion

41. A typical stress distribution is depicted in Figure 9, which shows the variation of horizontal stresses developed in three lifts. The figure indicates that between days 2 and 5, the horizontal compressive stresses in Lift 1 were gradually increased because of the increase in concrete temperatures. The maximum compressive stress was found near the center of the lift. When a cold new concrete lift was placed upon the relatively warm old lift, a sudden development of tensile stresses resulted at the lift interface. These stresses were gradually reduced because of creep and temperature rise due to hydration of cement. At Day 22, the tensile stress developed at the surface of Lift 3 was due to sudden ambient temperature drop at 16 September 1968 (see Figures 4 and 5).

42. The comparisons between calculated and measured strains are made at Element 235, where strain meters S052 and S053 are located. Figures 10 and 11 show the comparison between calculated and measured X-strains and Y-strains, respectively. The calculated stresses at Element 240 were compared with the stress meter Group AG G05 readings (Figures 12 and 13). Since the zero dates for stress and strain meters

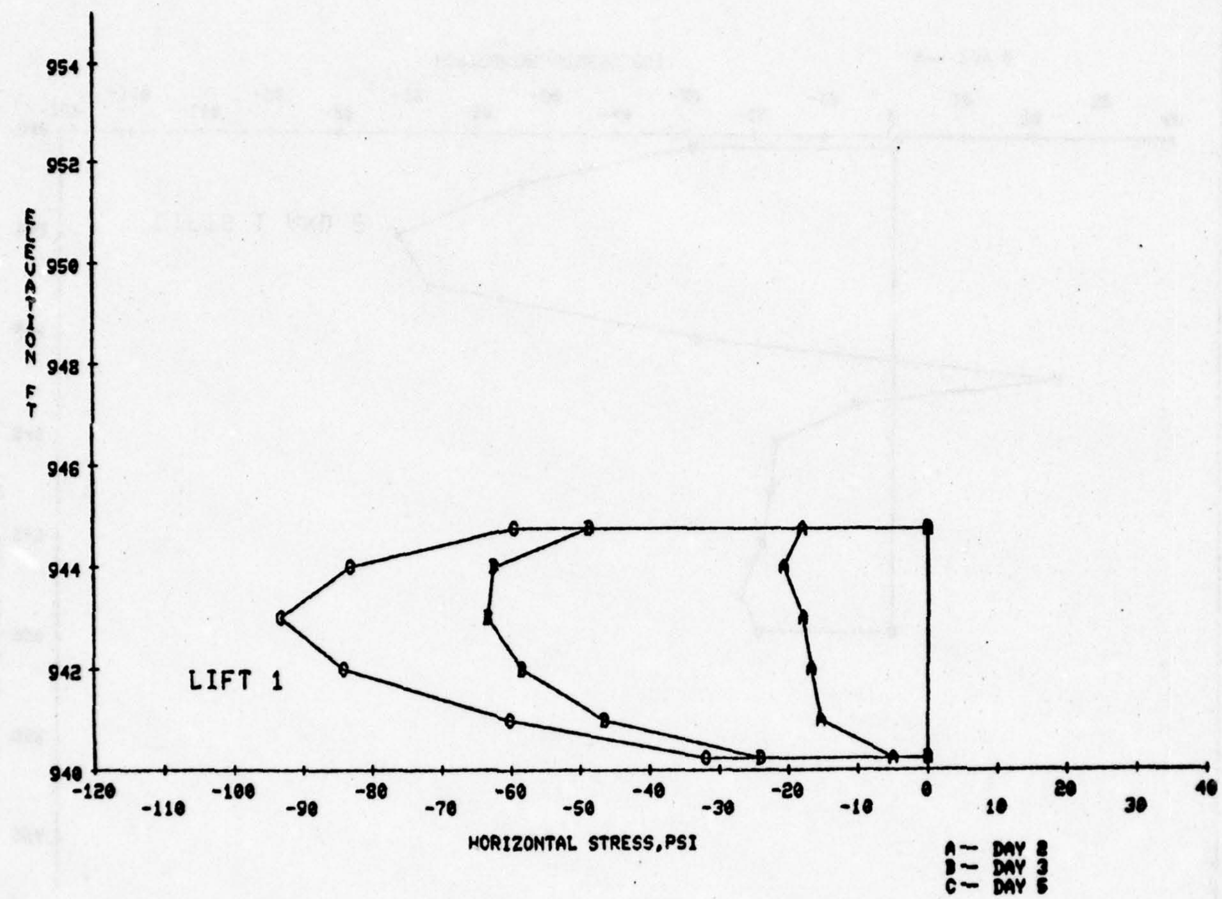

Figure 9. Distribution of Horizontal Stress on Vertical Section

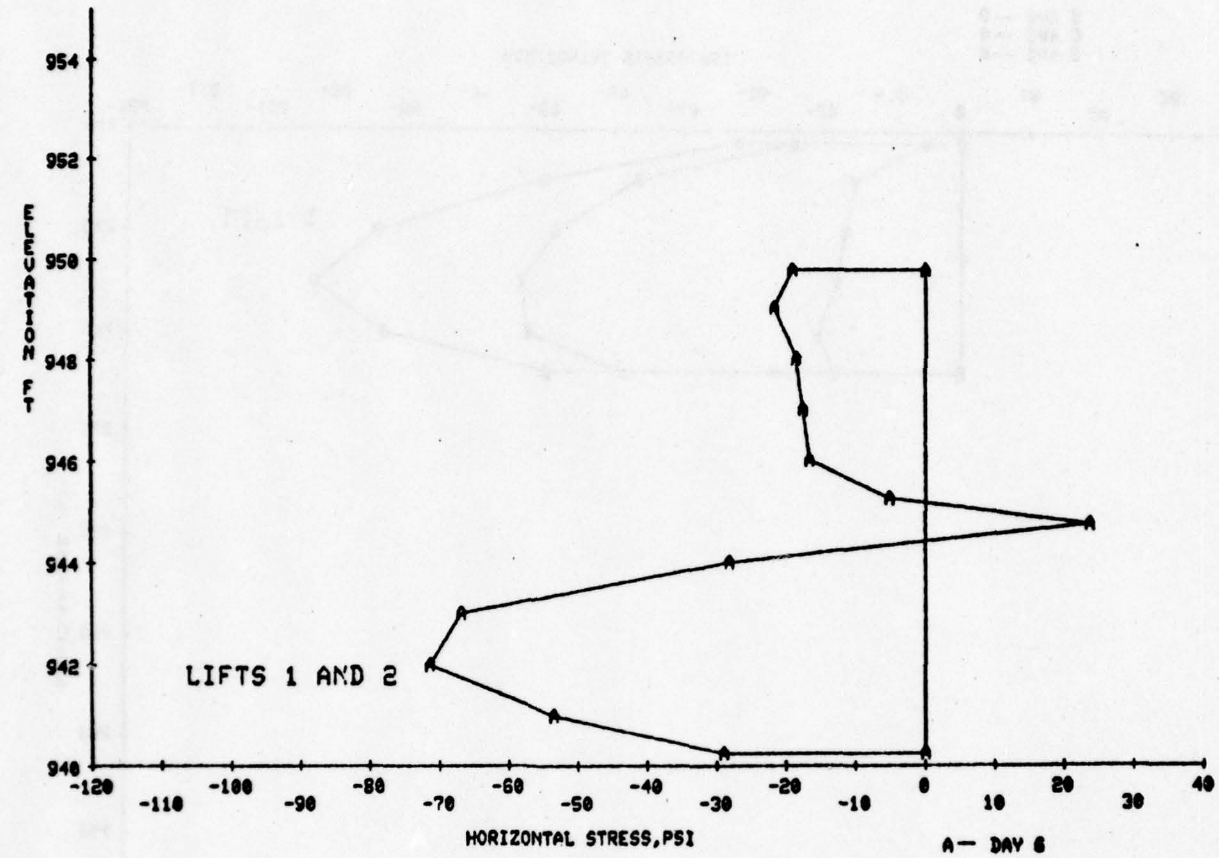

Figure 9 (Continued)

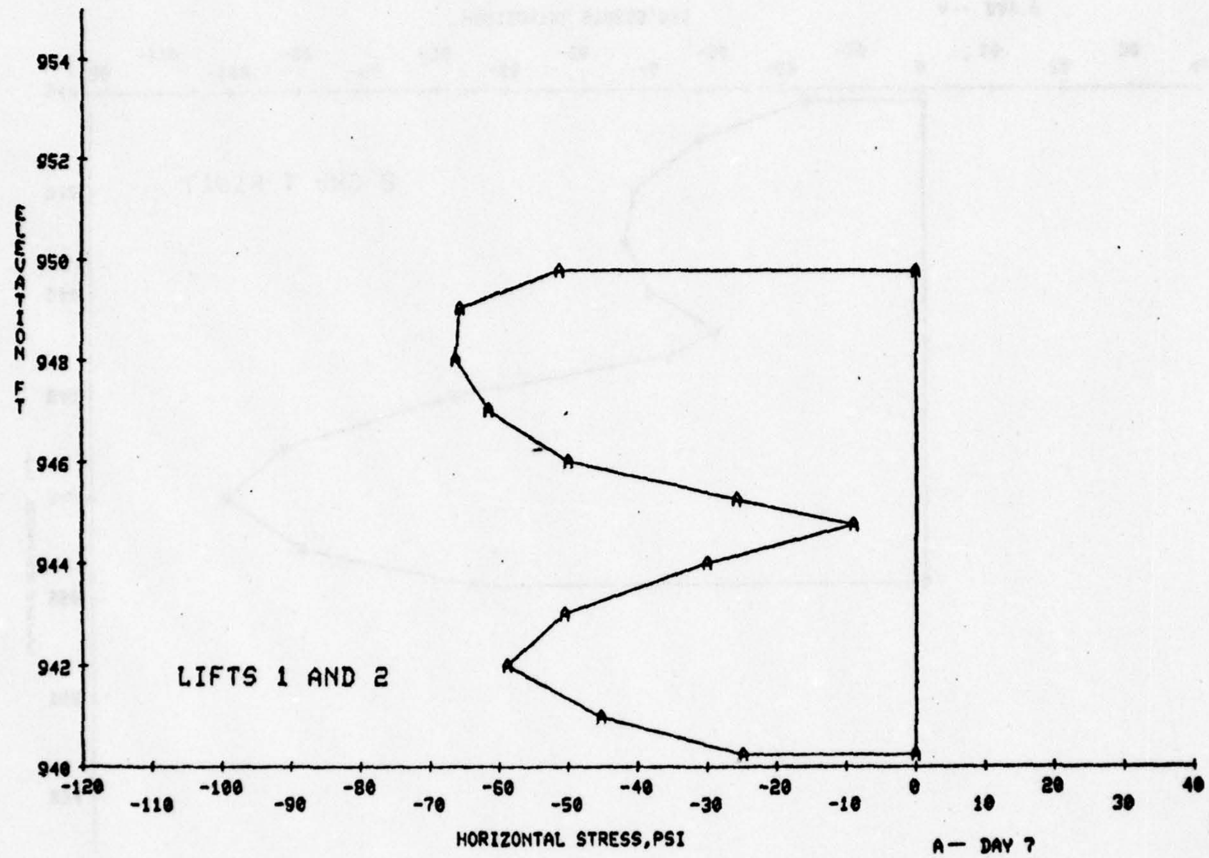

Figure 9 (Continued)

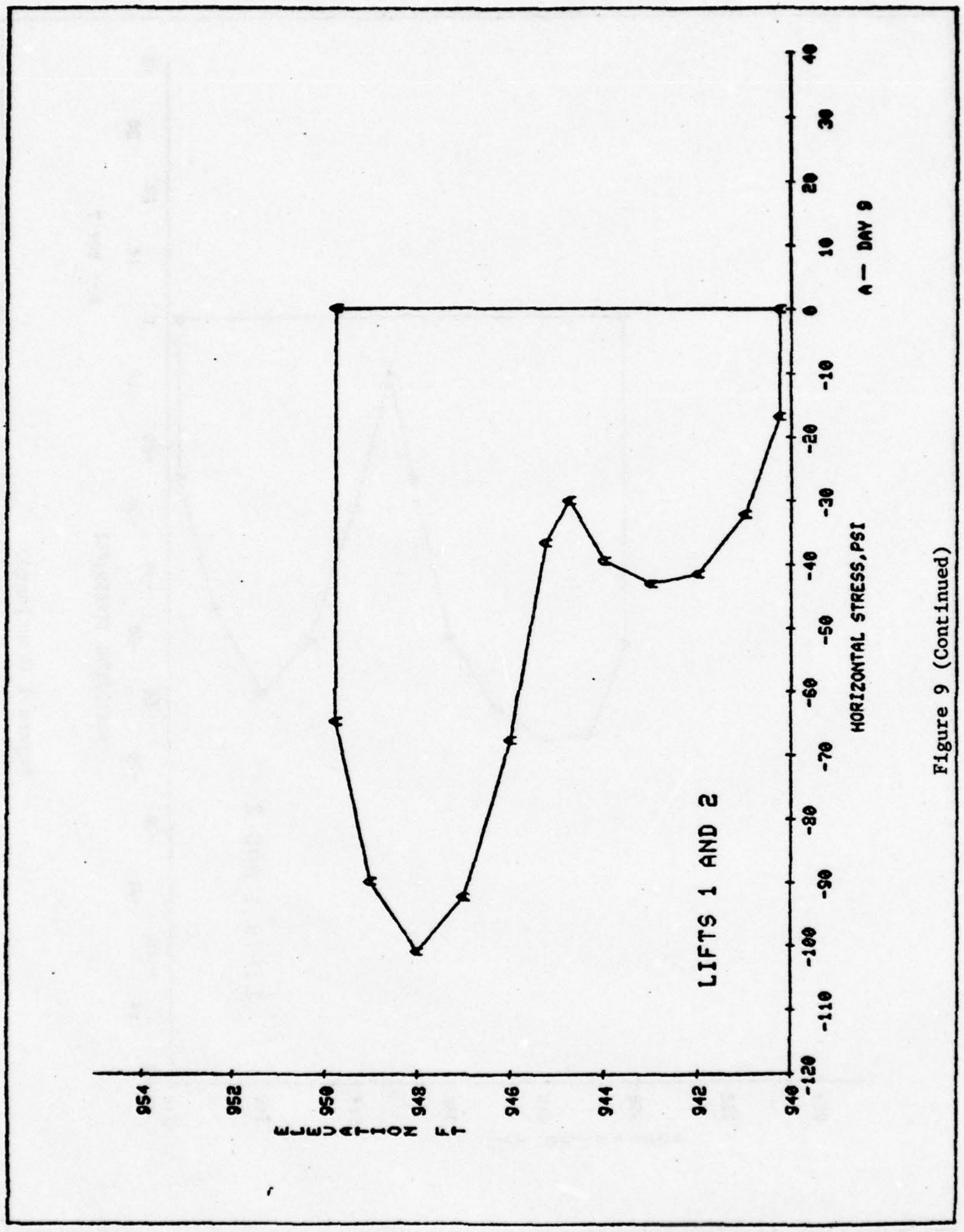

Figure 9 (Continued)

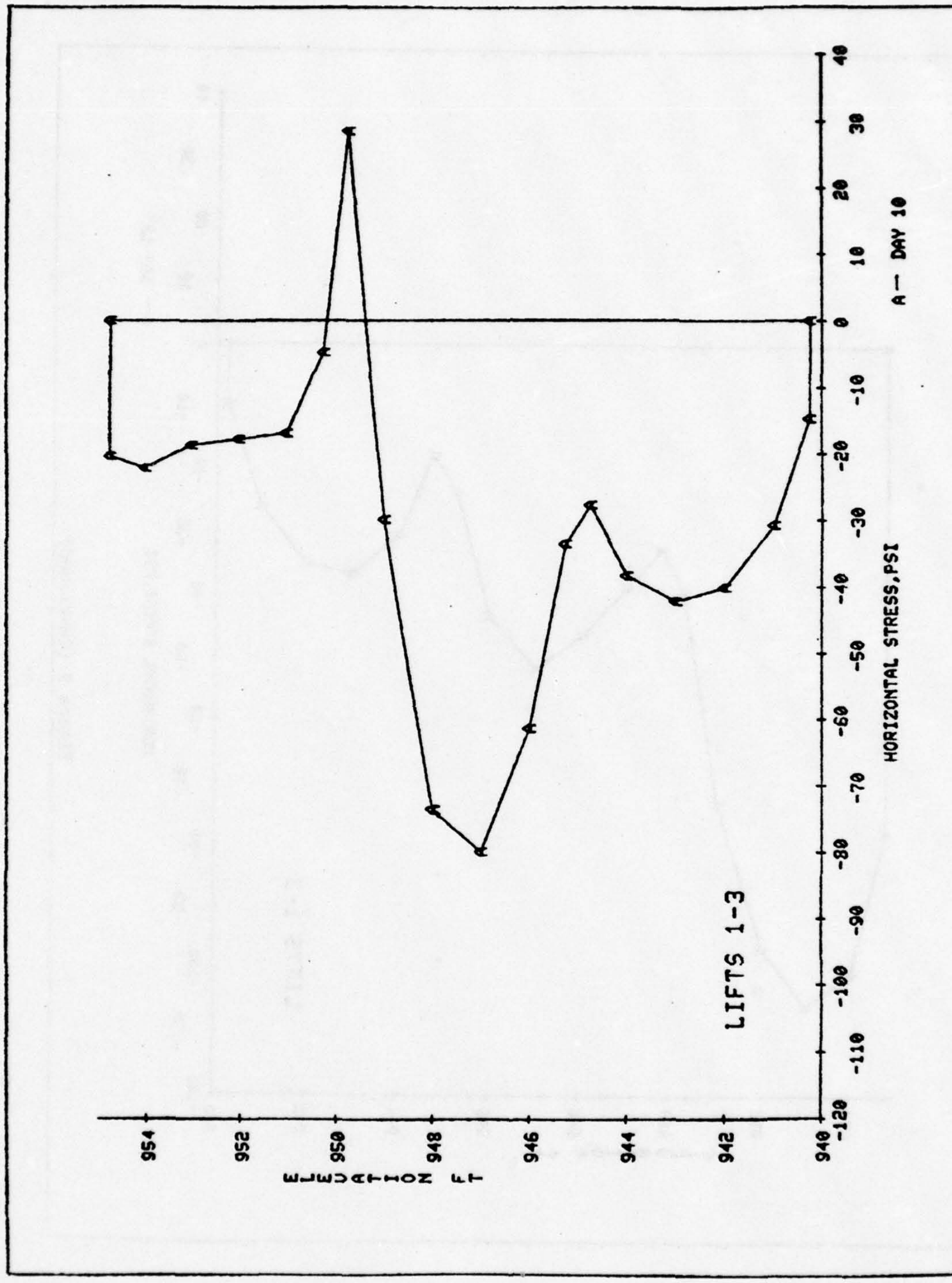

Figure 9 (Continued)

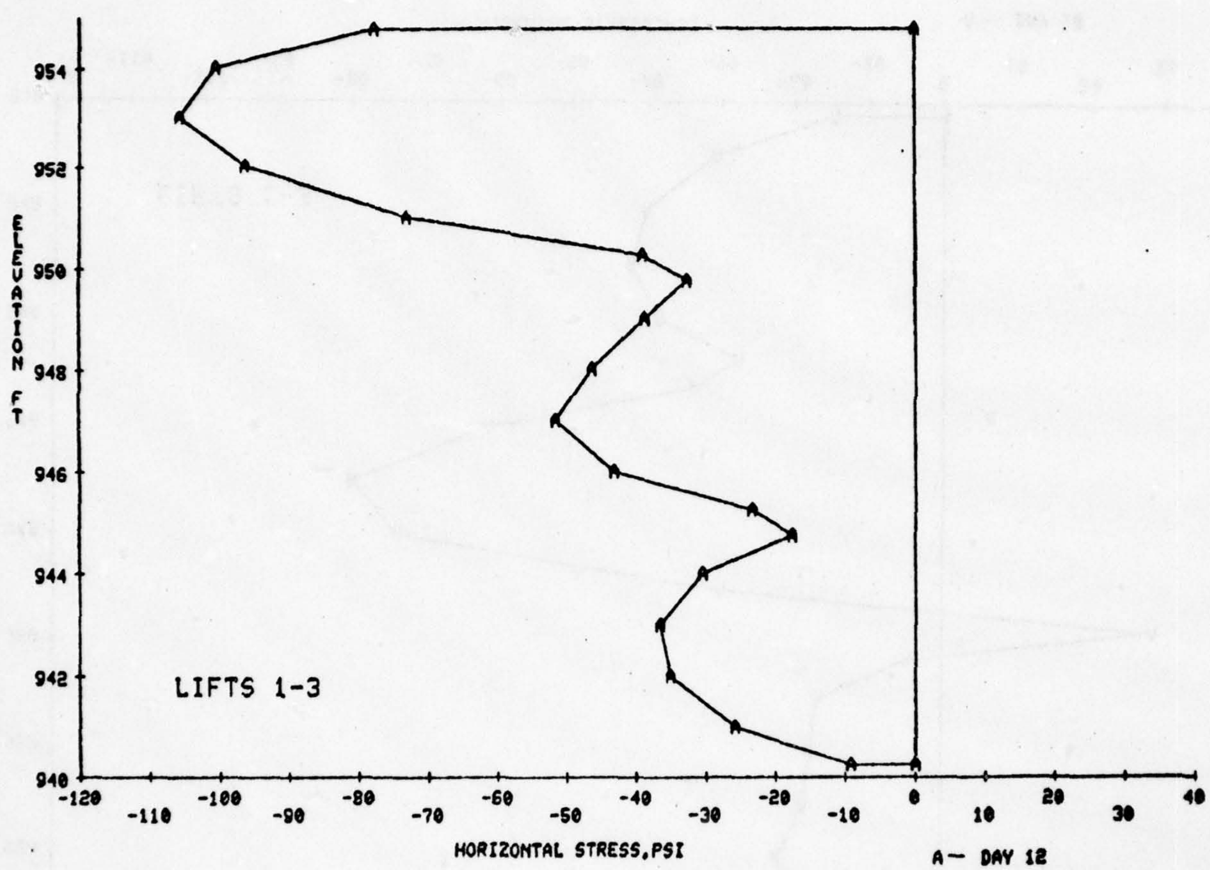

Figure 9 (Continued)

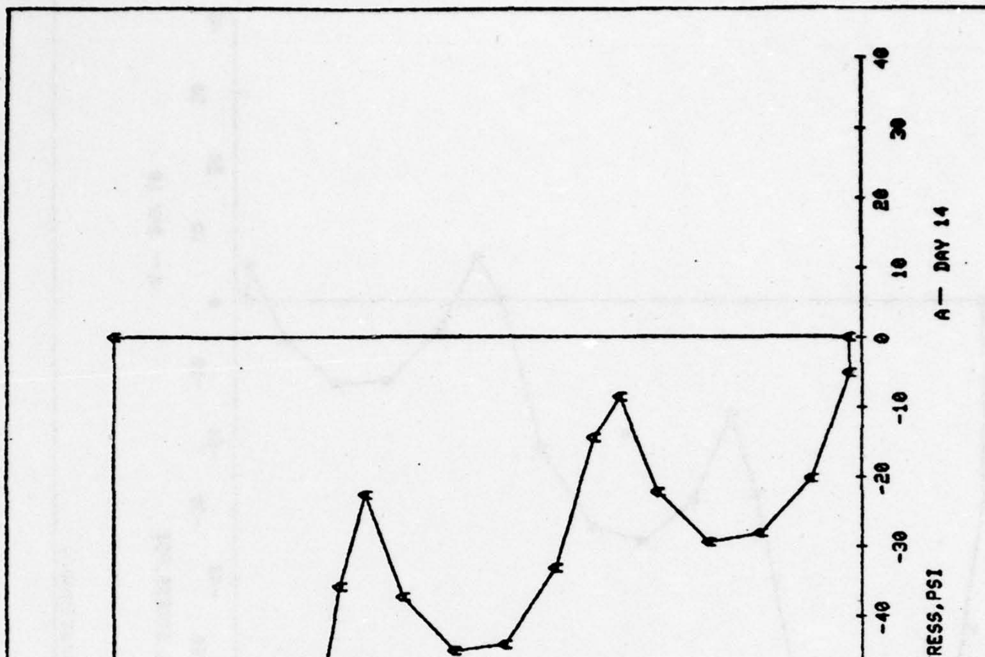

Figure 9 (Continued)

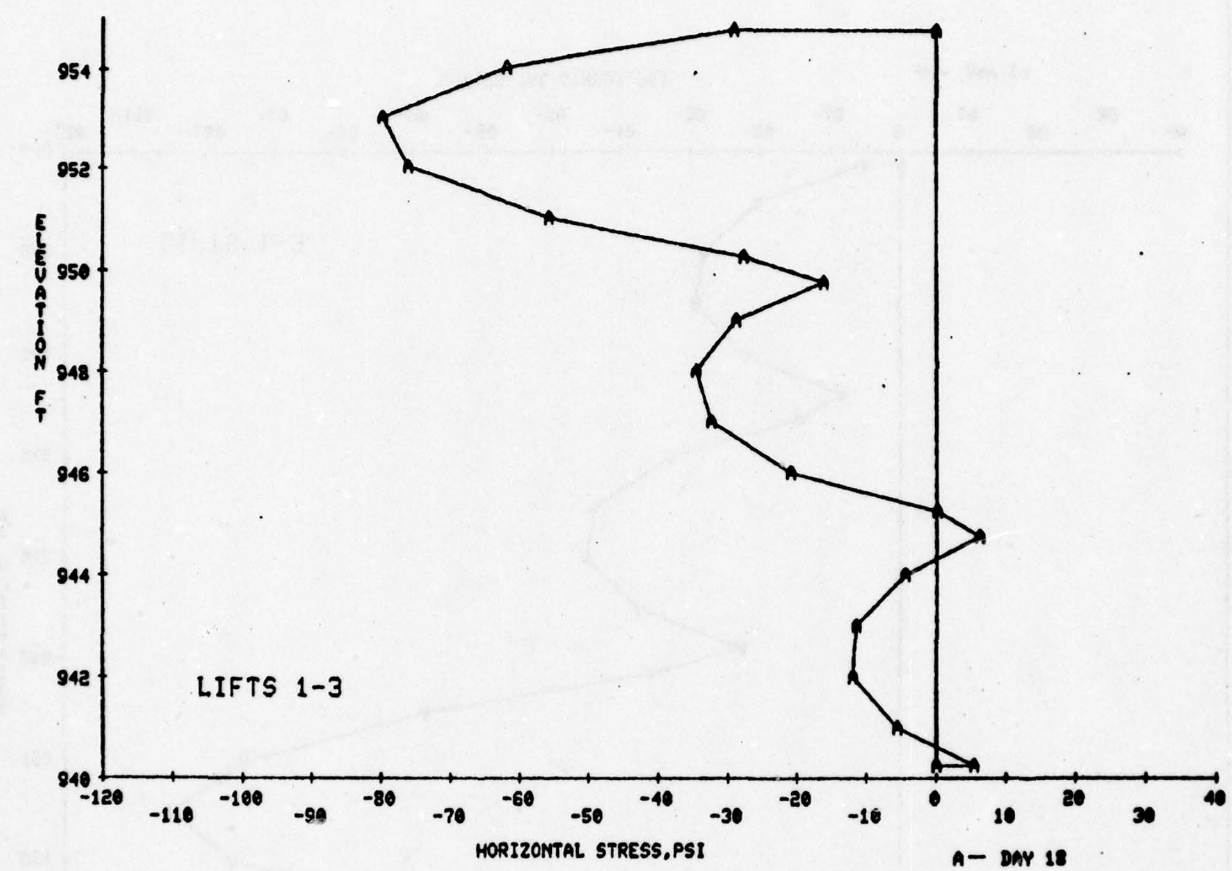

Figure 9 (Continued)

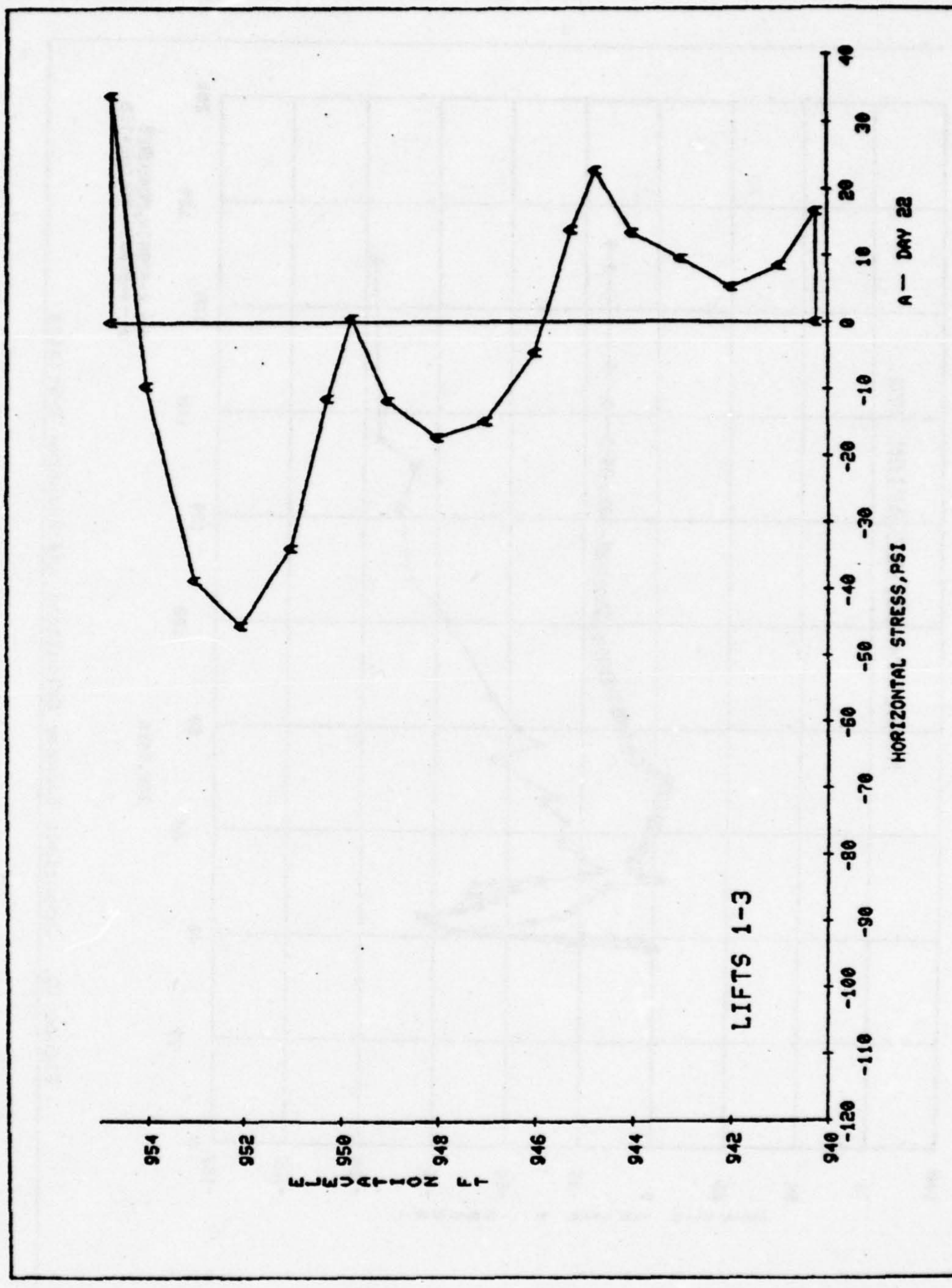

Figure 9 (Concluded)

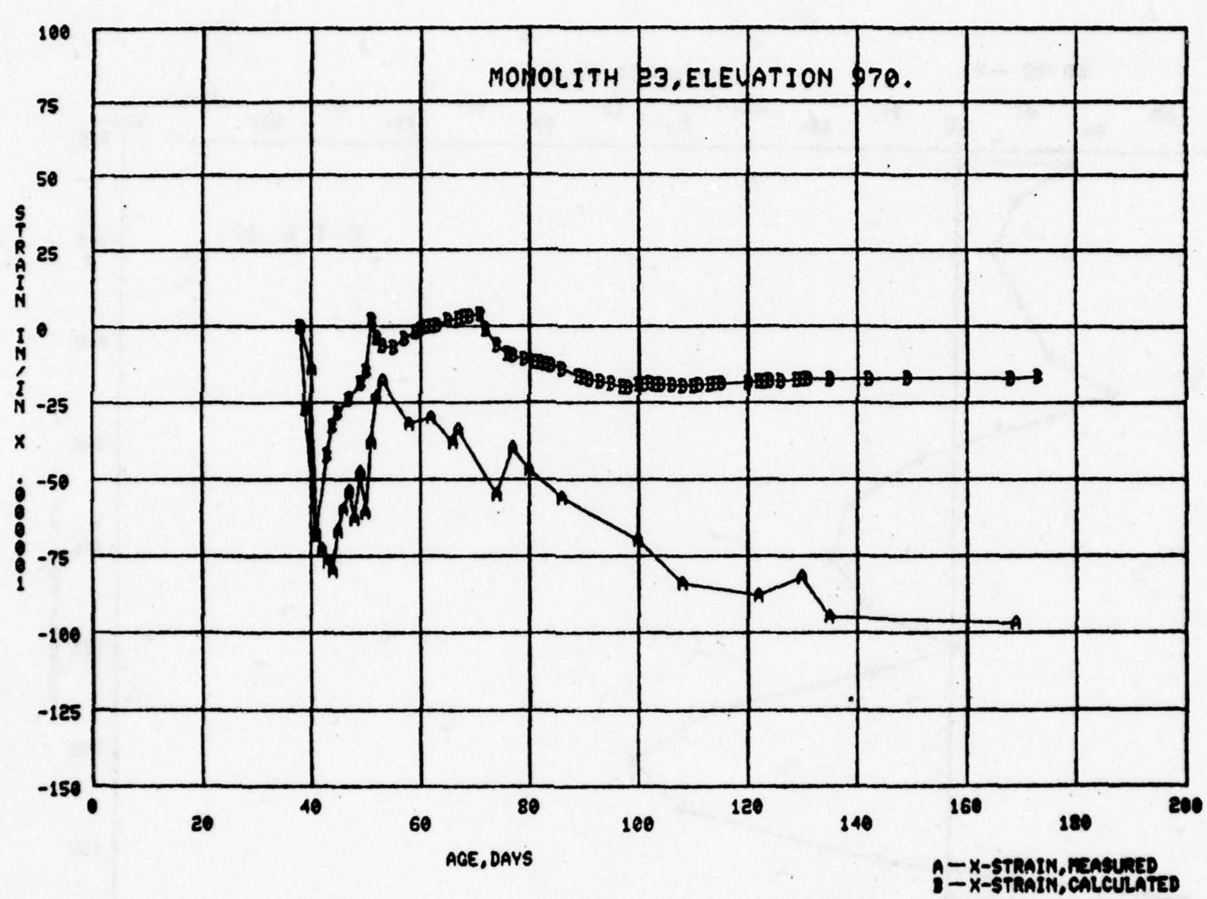

Figure 10. Comparison Between Calculated and Measured X-Strains

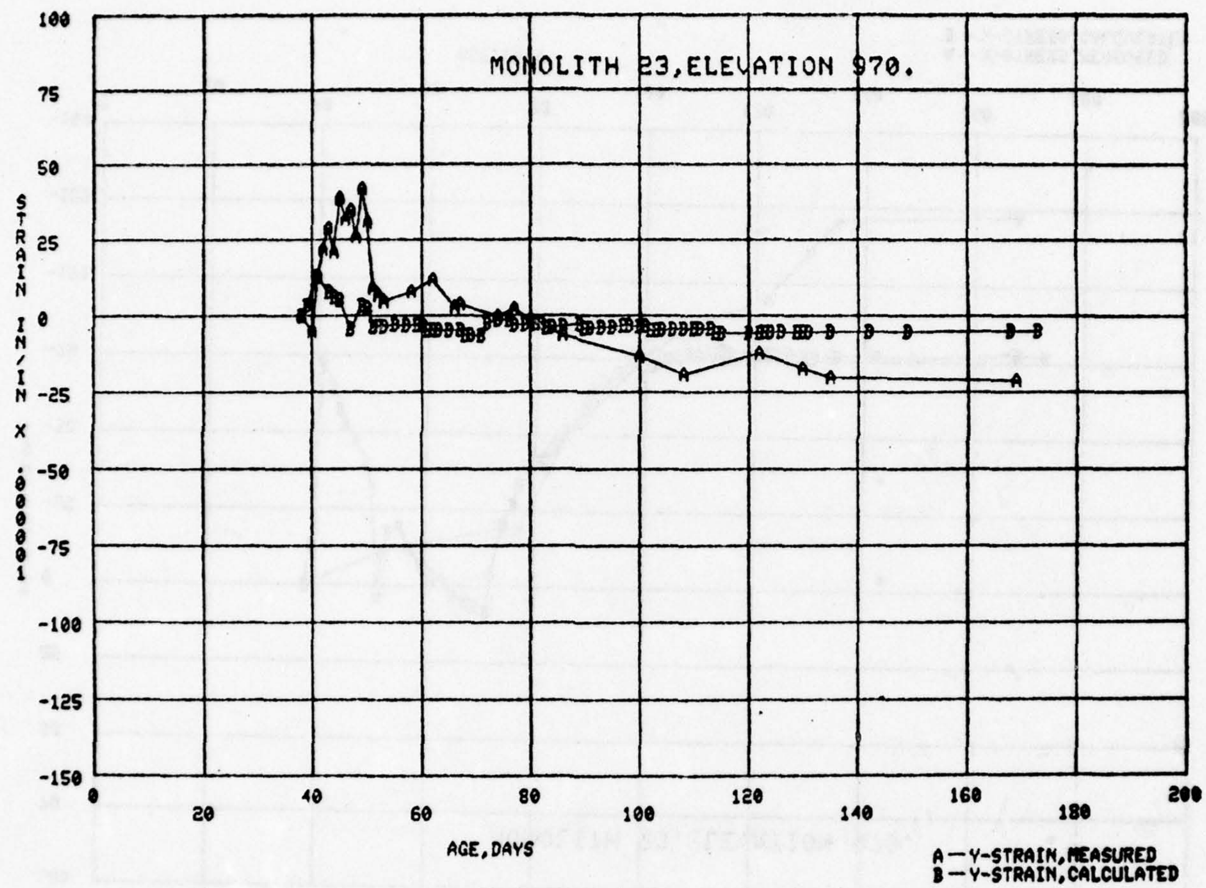

Figure 11. Comparison Between Calculated and Measured Y-Strains

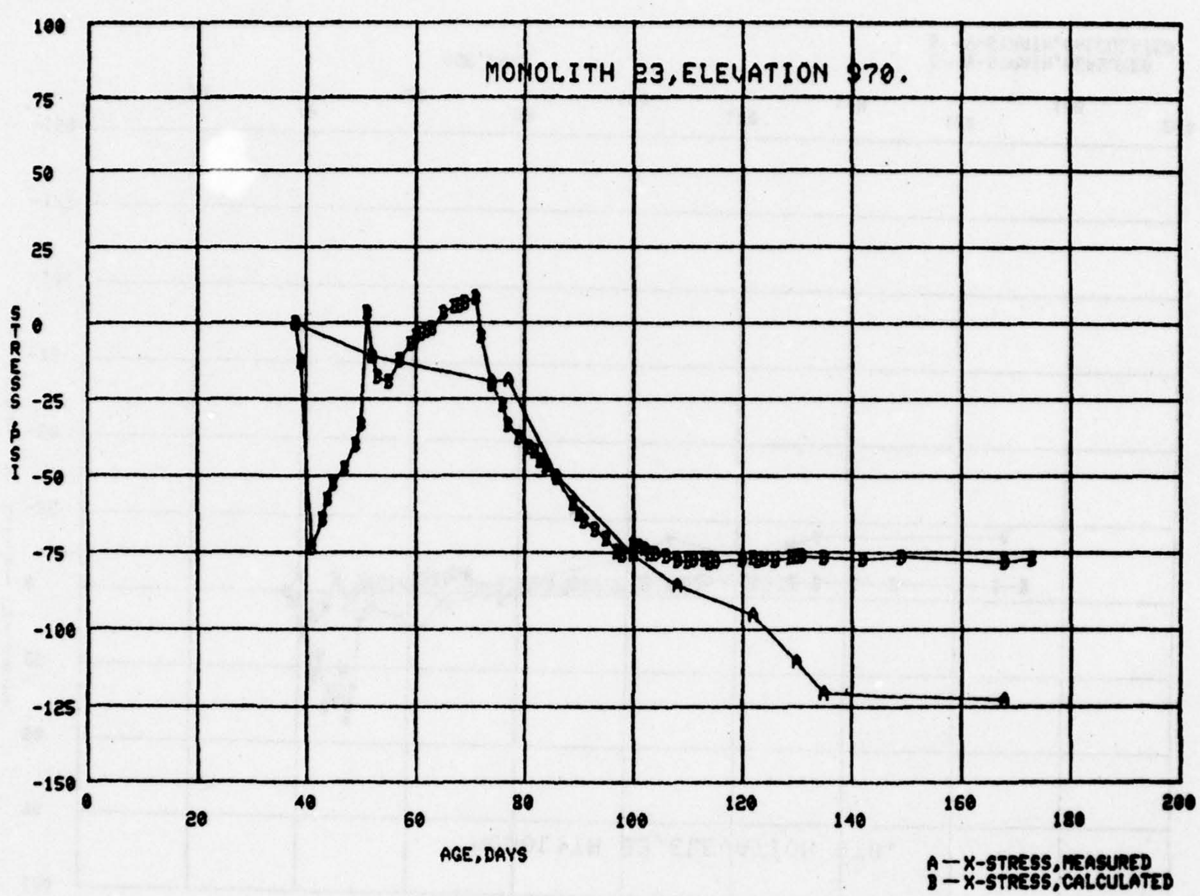

Figure 12. Comparison Between Calculated and Measured X-Stresses

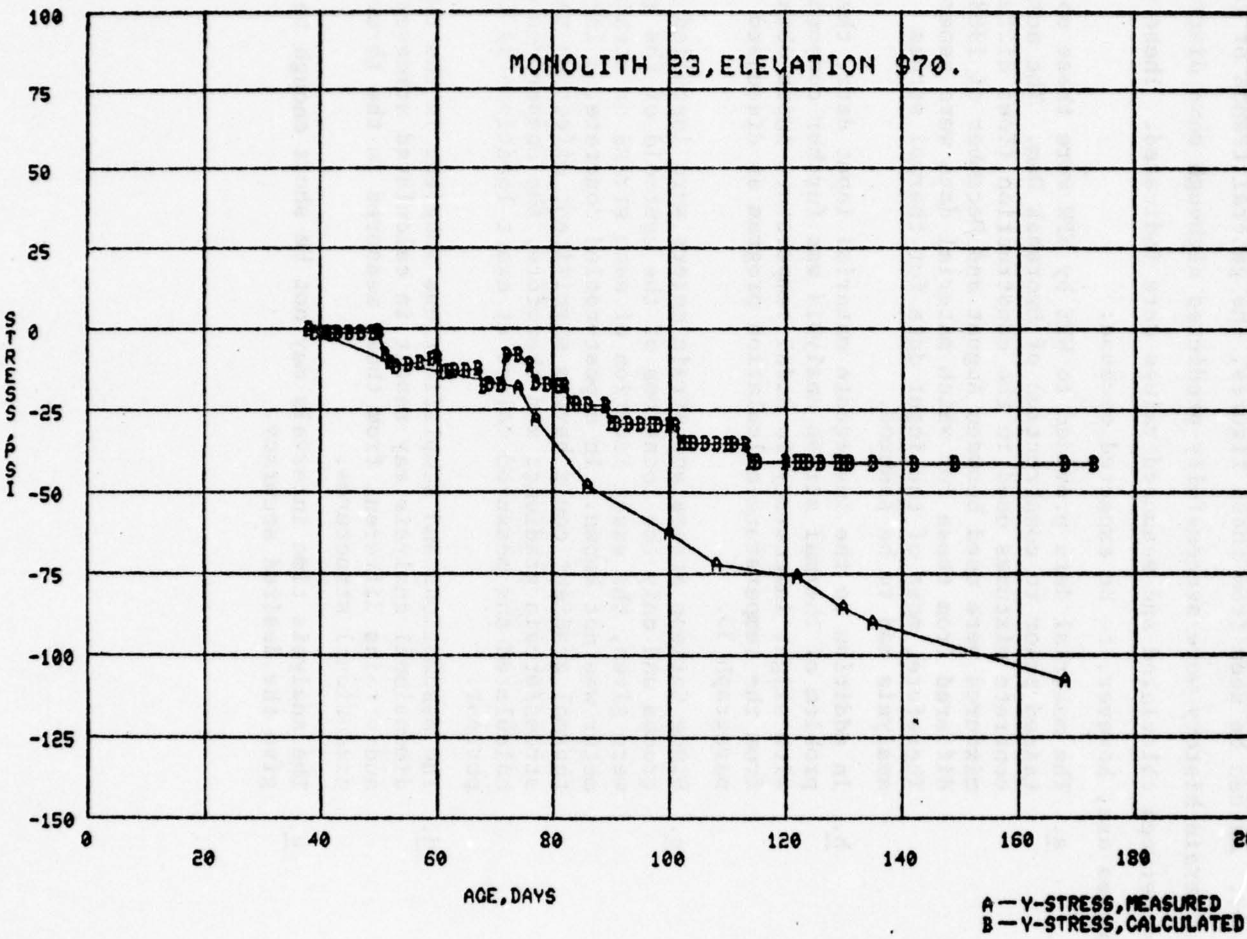

Figure 13. Comparison Between Calculated and Measured Y-Stresses

were several days after lift placement, these data were adjusted to match the calculated data at zero dates in order to obtain a more meaningful comparison.

43. As can be seen from these figures, the general trends of the stress/strain history were successfully predicted although some discrepancies between calculated and measured values were indicated. These discrepancies are, however, to be expected because:

- a. The material data provided to WES by NPW were those obtained prior to construction of Dworshak Dam. The actual concrete mixtures used in the construction (four different mixtures were used between August and December of 1968) differed from those for which material data were generated. Therefore, most of the input data for thermal stress analysis had to be assumed.
- b. In addition to the inadequate material input data, the problem of thermal stress analysis was further compounded with slight inaccuracy in nodal temperature input obtained from the temperature-calculation program as discussed in paragraph 33.
- c. Since Carlson stress and strain meters were installed in groups and only the locations of the centroid of the group were given, the exact location of each stress or strain meter was not known. In a post-cooled concrete, a large thermal gradient could have a significant effect on the stress/strain gradient; and therefore, the comparison of calculated and measured values at exact locations is important.
- d. The assumptions and simplifications inherent in the two-dimensional analysis may result in calculated stresses and strains different from those measured in the three-dimensional structures.
- e. The analysis time intervals may not be short enough to give the desired accuracy.

PART V: CONCLUSIONS AND RECOMMENDATIONS

44. Based on the results of this investigation, it can be concluded that the temperature and thermal stress calculation programs currently being used by the Corps are acceptable provided that complete thermal and material properties and environment data are available. This conclusion was drawn based upon the fact that the temperature and thermal stress analysis computer programs did successfully predict the trends of temperature and stress/strain history, respectively, although some discrepancies between calculated and measured values were noted.

45. Recommendations for further improvement of temperature and thermal stress/strain calculation programs are as follows.

- a. Further progress in temperature and thermal stress calculations for mass concrete structures is closely linked to the development of quantitative information on thermal, creep, and mechanical properties of concrete. The existing material data in the literature need to be analyzed and data storage and retrieval systems should be developed. The information on early age (e.g., zero through three days) thermal and mechanical properties is lacking at the current state of the art. Systematic tests to develop this information are recommended.

- b. Many advances have been made in the finite element techniques since the original development of the temperature and thermal stress calculation programs. It is recommended that these programs be updated to incorporate more efficient and accurate methodology, e.g., isoparametric elements, on-board band width minimizer, non-linear material properties, etc.

- c. The existing two-dimensional programs should be expanded to include thin-shell elements for simulating rigid steel forms. Axisymmetric analysis capability should also be added. Ultimately, three-dimensional finite element programs should be developed.

- d. The mathematical formulation of the creep mechanism used in the thermal stress analysis program was based on the McHenry equation.[5] Unfortunately, the derivation of the creep constants for the McHenry equation involves very time-consuming numerical analysis procedures. A simplified mathematical expression suitable for use with the finite element technique needs to be developed.

e. In the WES version of the thermal stress program, the stress-free temperature for an element is defined as the temperature at 8 hr after placement. A rational approach for determining stress-free temperatures needs to be developed.

f. In the existing programs, all thermal, creep, and mechanical properties are assumed to be temperature-independent. In the case of high cement-content concrete placed in a large mass, concrete temperatures as high as $120^{\circ}F$ can be expected, and in areas of cooling pipes, temperatures may be as low as $45^{\circ}F$. These extreme temperatures have significant effects on the rate of heat generation and other mechanical properties; therefore, temperature-dependent properties need to be considered in the programs.

g. In the current temperature program, any changes in insulating properties and cooling pipes are to be handled in a new lift. Therefore, a dummy lift must be introduced whenever the insulating properties or cooling water temperature varied. Simplified methods of modeling these changes within a lift should be developed.

h. In the creep analysis, the stress relaxation and creep determinations are carried out by a time increment sequence. It is necessary to establish a guidance for selecting optimum time intervals which are short enough to give desired accuracy but long enough to retain computational efficiency.

i. Solar radiation may have a significant effect on concrete temperatures in certain locations and times. This effect needs to be incorporated in the temperature calculation program.

REFERENCES

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2. Sandhu, R. S., Wilson, E. L., and Raphael, J. M., "Two-Dimensional Stress Analysis With Incremental Construction and Creep," Report No. 67-34, Dec 1967, Structural Engineering Laboratory, University of California, Berkeley, CA.

3. "Concrete Report - Dworshak Dam and Reservoir, North Fork Clearwater River, Idaho," U.S. Army Engineer District, Walla Walla, Wash. Apr 1972.

4. "Concrete Aggregate and Concrete Properties Investigations - Dworshak Dam and Reservoir, North Fork Clearwater River, Idaho," Design Memorandum No. 16, U.S. Army Engineer District, Walla Walla, 15 July 1965.

5. McHenry, D., "A New Aspect of Creep in Concrete and Its Application to Design," Proceedings, American Society for Testing and Materials, Vol 43, 1943.

6. Pirtz, D., "Creep Characteristics of Mass Concrete for Dworshak Dam," Structural Engineering Laboratory Report No. 652, University of California, 1965.

Table 1

Summary of Material Types

Lift	Date of Placement	Cement Content (sks/cu yd)	Fly Ash Content (% of cement wt)	Designated Material Type
Foundation	26 Aug 68	--	--	1
1	27 Aug	3.25	30	2
2	31 Aug	3.25	30	2
3	4 Sep	3.25	30	2
4	17 Sep	3.25	35	3
5	23 Sep	3.25	35	3
6	3 Oct	3.25	35	3
7	15 Oct	3.25	35	3
8	25 Oct	3.50	30	4
9	1 Nov	3.50	30	4
10	10 Nov	3.50	30	4
11	16 Nov	3.50	30	4
12	23 Nov	3.25	30	2
13	5 Dec	3.00	30	5
14	17 Dec	3.00	30	5

Table 2

Thermal Properties

Material Type	Specific Heat (Btu/lb-^{o}F)	Thermal Conductivity (Btu/hr-in.-^{o}F)	Density (lb/in.^{3})
1	0.220	0.113	0.089
2	0.220	0.113	0.089
3	0.220	0.113	0.089
4	0.220	0.118	0.089
5	0.220	0.107	0.089

Table 3

Adiabatic Temperature Rise Input

Time (Day)	Temperature (^{o}F)				
	Material Type 1	Material Type 2	Material Type 3	Material Type 4	Material Type 5
0.	0.	0.	0.	0.	0.
1.00	0.	9.4	8.8	10.4	8.4
2.00	0.	17.0	16.3	19.7	14.3
3.00	0.	20.7	19.9	22.4	19.0
4.00	0.	23.4	22.3	25.0	21.8
6.00	0.	26.4	25.2	27.8	25.0
7.00	0.	28.0	26.7	29.3	26.7
10.00	0.	31.4	29.7	32.9	29.9
14.00	0.	35.0	33.0	36.9	33.1
17.00	0.	37.0	34.9	39.1	34.9
21.00	0.	39.0	36.9	41.4	36.6
25.00	0.	40.8	38.7	43.5	38.1
28.00	0.	41.4	39.5	44.0	38.8
60.00	0.	49.0	46.6	51.4	45.7
90.00	0.	52.8	50.3	55.4	49.5
180.00	0.	59.5	56.8	62.2	55.8

Table 4

Cooling Water Removal Schedule

Day	Lift
22	1
26	2
30	3
43	4
49	5
59	6
71	7
81	8
88	9
97	10
103	11
110	12
122	13
123	14

Table 5

Thermal Conductivity of Insulation Material

Lift	Top Elevation (ft)	Conductivity (Btu/hr-in.-°F)
Foundation	940	--
1	945	--
2	950	--
3	955	--
4	960	0.003
5	965	0.003
6	970	0.003
7	975	0.003
8	980	0.002
9	985	0.002
10	990	0.002
11	995	0.002
12	1000	0.002
13	1005	0.002
14	1010	0.002

Table 6

Average Wind Velocity and Its Corresponding Convection Transfer Coefficient

Lift	Average Wind Velocity (fps)	Convection Transfer Coefficient (Btu/hr-in.^{2}-$^\circ$F)
Foundation	4.4	0.013
1	4.4	0.013
2	4.4	0.013
3	2.9	0.011
4	1.5	0.009
5	1.5	0.009
6	2.9	0.011
7	4.4	0.013
8	2.9	0.011
9	5.9	0.015
10	4.4	0.013
11	5.9	0.015
12	5.9	0.015
13	2.9	0.011
14	4.4	0.013

Table 7

Heat Transfer Coefficient

Lift	Heat Transfer Coefficient (Btu/hr-in.^{2}-^oF)
Foundation	0.0133
1	0.0133
2	0.0133
3	0.0111
4	0.0023
5	0.0023
6	0.0024
7	0.0024
8	0.0017
9	0.0018
10	0.0017
11	0.0018
12	0.0018
13	0.0017
14	0.0017

Table 8

Mechanical Input Properties - Material Type 1

Time (day)	Modulus of Elasticity (psi)	Poisson's Ratio	Coefficient of Thermal Expansion (in./^{o}F)
0	2.8×10^{6}	0.20	5.5×10^{-6}
200	2.8×10^{6}	0.20	5.5×10^{-6}

Table 9

Mechanical Input Properties - Material Type 2

Time (day)	Modulus of Elasticity (10^6 x psi)	Poisson's Ratio	Coefficient of Thermal Expansion (10^{-6} x in./^oF)
0	0	0	5.48
0.5	0.3	0.17	5.48
1.0	0.6	0.17	5.48
1.5	0.9	0.17	5.48
2.0	1.10	0.17	5.48
2.5	1.22	0.17	5.48
3.0	1.35	0.17	5.48
4.0	1.53	0.17	5.48
5.0	1.70	0.17	5.48
6.0	1.82	0.17	5.48
7.0	1.90	0.17	5.48
8.0	2.00	0.17	5.48
12.0	2.30	0.17	5.48
16.0	2.49	0.17	5.48
20.0	2.62	0.17	5.48
28.0	2.85	0.17	5.48
36.0	3.02	0.18	5.48
44.0	3.15	0.19	5.48
52.0	3.26	0.20	5.48
60.0	3.35	0.20	5.48
70.0	3.45	0.21	5.48
80.0	3.53	0.21	5.48
90.0	3.62	0.22	5.48
100.0	3.70	0.22	5.48
120.0	3.80	0.22	5.48
140.0	3.90	0.22	5.48
160.0	4.00	0.22	5.48
180.0	4.09	0.22	5.48
200.0	4.15	0.22	5.48

Table 10

Mechanical Properties Input - Material Type 3

Time (day)	Modulus of Elasticity (10^6 x psi)	Poisson's Ratio	Coefficient of Thermal Expansion (10^6 x in./^oF)
0	0	0	5.48
0.5	0.25	0.17	5.48
1.0	0.55	0.17	5.48
1.5	0.85	0.17	5.48
2.0	1.05	0.17	5.48
2.5	1.17	0.17	5.48
3.0	1.30	0.17	5.48
4.0	1.48	0.17	5.48
5.0	1.65	0.17	5.48
6.0	1.77	0.17	5.48
7.0	1.85	0.17	5.48
8.0	1.95	0.17	5.48
12.0	2.25	0.17	5.48
16.0	2.44	0.17	5.48
20.0	2.57	0.17	5.48
28.0	2.80	0.17	5.48
36.0	2.97	0.18	5.48
44.0	3.10	0.19	5.48
52.0	3.21	0.20	5.48
60.0	3.30	0.20	5.48
70.0	3.40	0.21	5.48
80.0	3.48	0.21	5.48
90.0	3.57	0.22	5.48
100.0	3.65	0.22	5.48
120.0	3.75	0.22	5.48
140.0	3.85	0.22	5.48
160.0	3.95	0.22	5.48
180.0	4.40	0.22	5.48
200.0	4.10	0.22	5.48

Table 11

Mechanical Properties Input - Material Type 4

Time (day)	Modulus of Elasticity (10^6 x psi)	Poisson's Ratio	Coefficient of Thermal Expansion (10^6 x in./^{o}F)
0	0	0	5.50
0.5	0.4	0.17	5.50
1.0	0.8	0.17	5.50
1.5	1.1	0.17	5.50
2.0	1.3	0.17	5.50
2.5	1.45	0.17	5.50
3.0	1.58	0.17	5.50
4.0	1.75	0.17	5.50
5.0	1.90	0.17	5.50
6.0	2.03	0.17	5.50
7.0	2.14	0.17	5.50
8.0	2.22	0.17	5.50
12.0	2.50	0.17	5.50
16.0	2.70	0.17	5.50
20.0	2.83	0.17	5.50
28.0	3.06	0.17	5.50
36.0	3.22	0.18	5.50
44.0	3.35	0.19	5.50
52.0	3.48	0.20	5.50
60.0	3.58	0.20	5.50
70.0	3.66	0.21	5.50
80.0	3.75	0.21	5.50
90.0	3.82	0.22	5.50
100.0	3.90	0.22	5.50
120.0	4.00	0.22	5.50
140.0	4.10	0.22	5.50
160.0	4.20	0.22	5.50
180.0	4.30	0.22	5.50
200.0	4.35	0.22	5.50

Table 12

Mechanical Properties Input - Material Type 5

Time (day)	Modulus of Elasticity (10^6 x psi)	Poisson's Ratio	Coefficient of Thermal Expansion (10^{-6} x in./^oF)
0	0	0	5.40
0.5	0.2	0.17	5.40
1.0	0.4	0.17	5.40
1.5	0.7	0.17	5.40
2.0	0.9	0.17	5.40
2.5	1.03	0.17	5.40
3.0	1.16	0.17	5.40
4.0	1.35	0.17	5.40
5.0	1.50	0.17	5.40
6.0	1.62	0.17	5.40
7.0	1.72	0.17	5.40
8.0	1.80	0.17	5.40
12.0	2.10	0.17	5.40
16.0	2.30	0.17	5.40
20.0	2.42	0.17	5.40
28.0	2.68	0.17	5.40
36.0	2.81	0.18	5.40
44.0	2.95	0.19	5.40
52.0	3.07	0.20	5.40
60.0	3.16	0.20	5.40
70.0	3.27	0.21	5.40
80.0	3.33	0.21	5.40
90.0	3.42	0.22	5.40
100.0	3.50	0.22	5.40
120.0	3.60	0.22	5.40
140.0	3.70	0.22	5.40
160.0	3.80	0.22	5.40
180.0	3.90	0.22	5.40
200.0	3.95	0.22	5.40

Table 13

Constants for Creep Equation

Time	a_1	a_2
0	0.960×10^{-6}	0.463×10^{-6}
1	$.920 \times 10^{-6}$	$.475 \times 10^{-6}$
4	$.545 \times 10^{-6}$	$.565 \times 10^{-6}$
6	$.405 \times 10^{-6}$	$.500 \times 10^{-6}$
8	$.353 \times 10^{-6}$	$.442 \times 10^{-6}$
10	$.318 \times 10^{-6}$	$.395 \times 10^{-6}$
16	$.250 \times 10^{-6}$	$.289 \times 10^{-6}$
20	$.219 \times 10^{-6}$	$.248 \times 10^{-6}$
24	$.191 \times 10^{-6}$	$.225 \times 10^{-6}$
28	$.170 \times 10^{-6}$	$.215 \times 10^{-6}$
32	$.147 \times 10^{-6}$	$.208 \times 10^{-6}$
44	$.105 \times 10^{-6}$	$.191 \times 10^{-6}$
60	$.690 \times 10^{-7}$	$.170 \times 10^{-6}$
76	$.440 \times 10^{-7}$	$.150 \times 10^{-6}$
100	$.220 \times 10^{-7}$	$.122 \times 10^{-6}$
200	0.200×10^{-7}	0.100×10^{-6}

APPENDIX A: TWO-DIMENSIONAL TEMPERATURE CALCULATION PROGRAM (WES VERSION)

```
$      IDENT    80C846,B-DORSHK TEMP CALC 13 JUNE 1978
$      OPTION   FORTRAN
$      FORTY    XREF,MAP,DECK
$      LIMITS   05,35K,,3000
$      FILE     C*,X3S,1L,NEW,TOBJFIL
C     PROGRAM NO 42 K5 G403
C     TEMPERATURE PROGRAM WITH PLOTTER OUTPUT OF EXTRA OUTPUT NODES
C
      PARAMETER MAXN=580,MAXBW=9,MXE=480
      COMMON NODAY,NUMEL,NCBH,NCPH,NUMMAT,NDT,INTER,DT,TIME,NUMNP,NUME,
     1  NUMOC,PLTIME,B(MAXN),X(MAXN),Y(MAXN),T(MAXN),D(MAXN),TT(MAXN),
     2  IX(MXE,5),PLTM(MXE),VOL(MXE),HED(16),LM(5),E(3,3),KX(4),S(5,5),
     3  XCOND(10),SPHT(10),DENS(10),QX(35,2,10),WSTEP(10),ET(100,2,3),
     4  IC(210),JC(210),HC(210),THC(210),CL(210),ISPAN,PLACET,NELP,
     5  IP(210),HP(210),TP(210),THP(210),IETC(210),NE,TEMPMAX,PDAY,
     6 PEAKDAY,NODEPEAK,PEAKTEMP,NPEAKNDE,TSF(MXE)
      COMMON /OUTPUT/ NNODE,MCOUNT,NODE(30),LIFT(30),TITLE(16),IPUNCH,
     1 SOLC(5),NPLOT,NDATE(2)
      COMMON/SYMARG/NUMN,MBAND,A(MAXN,MAXBW),Q(MAXN)
      COMMON /CHANN/ MPLOT
      COMMON/NPRIN/NTAPE11
      WRITE(08,700)
  700 FORMAT(//" STRESS FREE ELEM. TEMP AT 6 HR AFT PLACEMENT"//)
      WRITE(09,700)
C
      CALL DECK
      WRITE(6,200)TEMPMAX,PDAY,NPEAKNDE
  200 FORMAT(" ********************************** PEAK TEMPERATURE",
     1 "***********************************",//
     2 " THE PEAK TEMPERATURE FOR THIS RUN =",F7.2," OCCURS ON",
     3 " THE ",E6.1," DAY AT NODE NO. = ",I4,//"********",
     4 "**************************************************************")
  400 FORMAT(1X,16A4)
      CALL TPLOT
      END FILE 11
      WRITE (06,9050)
 9050 FORMAT ('0PROCESSING COMPLETE')
      STOP
      END
      SUBROUTINE DECK
C     TRANSIENT TEMPERATURE ANALYSIS OF CONCRETE STRUCTURES
C     BY THE FINITE ELEMENT METHOD
C
C     PROGRAM NO 42 K5 G403
C
C     CORPS OF ENGINEERS
C     NORTH PACIFIC DIVISION
C     WALLA WALLA DISTRICT
C
C     PROGRAM BY DR EDWARD L WILSON  UNIVERSITY OF CALIF. BERKELEY
C     ADAPTED TO IBM 360/50 BY GRANT ANDERSON
C
```

```
C
      PARAMETER MAXN=580,MAXBW=9,MXE=480
      COMMON NODAY,NUMEL,NCBH,NCPF,NUMMAT,NDT,INTER,DT,TIME,NUMNP,NUME,
     1  NUMOC,PLTIME,B(MAXN),X(MAXN),Y(MAXN),T(MAXN),D(MAXN),TT(MAXN),
     2  IX(MXE,5),PLTM(MXE),VOL(MXE),HED(16),LM(5),E(3,3),KX(4),S(5,5),
     3  COND(10),SPHT(10),DENS(10),QX(35,2,10),ISTOP(10),ET(100,2,3),
     4  IC(210),JC(210),HC(210),TMC(210),CL(210),ISRAN,PLACET,NELP,
     5  IP(210),HP(210),TP(210),TMP(210),IETC(210),NE,TEMPMAX,PDAY,
     6 PEAKDAY,NODEPEAK,PEAKTEMP,NPEAKNDE,TSF(MXE)
      COMMON /OUTPUT/ NNODE,MCOUNT,NODE(30),LIFT(30),TITLE(16),IPUNCH,
     1 SOLC(3),NPLOT,NDATE(2)
      COMMON/SYMARG/NUMN,MBAND,A(MAXN,MAXBW),B(MAXN)
      COMMON /CHANN/ NCHANN
      COMMON/NPBIN/NTAPE11
      DIMENSION IR(5),TR(5),XUN(35),YUN(35)
      REWIND 11
C
      NF=20
      TEMPMAX=0.
C*********************************************************************
C     READ AND PRINT OF CONTROL INFORMATION
C*********************************************************************
   50 READ(NF,999)HED
      READ(NF,1000)NUMNP,NUMEL,NUMMAT,NUMOC,NUMET1,NUMET2,
     1 NUMET3,NNODE,TIME,ISPAN,ICARDS,IPUNCH,SOLC(1),SOLC(2),
     2 SOLC(3),NPLOT,NCHANN
      WRITE(7,999)HED
      WRITE(08,999)HED
      WRITE(09,999)HED
      WRITE(7,1000)NUMNP,NUMEL,NUMMAT,NUMOC,NUMET1,NUMET2,
     1 NUMET3,NNODE,TIME,ISPAN,ICARDS,IPUNCH,SOLC(1),
     2 SOLC(2),SOLC(3),NPLOT,NCHANN
      WRITE (6,2011)
   58 WRITE (6,2000)        HED,NUMNP,NUMEL,NUMMAT,NUMOC,NUMET1,NUMET2,
     1 NUMET3
      NODAY=0
C*****READ OUTPUT CONTROL-NOCARD,NELCARD,NTAPE11 -IF EACH OR ANY
C     ARE = 1, THEN CARDS ARE PUNCHED FOR NODES AND ELEMENTS, AND
C     OUTPUT TAPE CREATED RESPECTIVELY,  =0 NO ACTION TAKEN,
      READ(NF,2400)NOCARD,NELCARD,NTAPE11,ISCALE
 2400 FORMAT(4I5)
      WRITE(7,2400)NOCARD,NELCARD,NTAPE11,ISCALE
C*********************************************************************
C     READ OR GENERATE NODAL POINT INFORMATION
C*********************************************************************
      WRITE (6,2001)
      L=1
   60 READ(NF,1001)N,NROWN,X(N),Y(N),TT(N),NUMEV,NUMEVT,MOD,
     1 NLIM
      WRITE(7,1001)N,NROWN,X(N),Y(N),TT(N),NUMEV,NUMEVT,MOD,
     1 NLIM
      IF(ISCALE.EQ.0)GO TO 5000
```

```
      X(N)=X(N)*12.
      Y(N)=Y(N)*12.
 5000 FACX=0.0
      FACY=0.0
      DIFF=N+1-L
      IF(NUMEV.EQ.0)GO TO 81
      IF(NUMEV.GE.NROWN.AND.NUMEV.EQ.1)GO TO 82
      GO TO 81
 82   XUN(NROWN)=X(N)
      YUN(NROWN)=Y(N)
 81   IF(N-L)65,80,70
   65 WRITE (6,2020) N
      GO TO 60
 70   IF(NUMEV.EQ.2)GO TO 83
      DX=(X(N)-X(L-1))/DIFF
      DY=(Y(N)-Y(L-1))/DIFF
      DP=(TT(N)-TT(L-1))/DIFF
 75   IF(NUMEV.EQ.2)GO TO 84
      X(L)=X(L-1)+DX
      Y(L)=Y(L-1)+DY
      TT(L)=TT(L-1)+DP
      GO TO 80
 83   LL=2
 84   X(L)=X(L-1)+(XUN(LL)-XUN(LL-1))
      Y(L)=Y(L-1)+(YUN(LL)-YUN(LL-1))
      TT(L)=0.0
      LL=LL+1
      GO TO 80
  390 L1=N+1
      IF(FACX.LE.0.0) FACX=1.0
      IF(FACY.LE.0.0) FACY=1.0
      WRITE (6,2090) MOD,NLIM,FACX,FACY
  400 N=N+1
      N1=N-MOD
      N2=N1-MOD
      IF((N1.GT.0).AND.(N2.GT.0)) GO TO 405
      WRITE (6,2130)
      CALL EXIT
  405 X(N)=X(N1)+FACX*(X(N1)-X(N2))
      Y(N)=Y(N1)+FACY*(Y(N1)-Y(N2))
      TT(N)=0.0
      IF(N.LT.NLIM) GO TO 400
      L=N
      MOD=0
   80 WRITE(6,2002) (K,X(K),Y(K),TT(K),K=L1,L)
      L=L+1
      L1=L
      IF(MOD.GT.0) GO TO 390
      IF (N-L) 90,60,75
   90 IF (NUMNP+1-L) 100,100,60
  100 CONTINUE
      IF(NTAPE11.EQ.0)GO TO 3000
```

```
      WRITE(11)(N,X(N),Y(N),N=1,NUMNP)
 3000 IF(NOCARD.EQ.0)GO TO 2410
      PUNCH 2500,(N,X(N),Y(N),TT(N),N=1,NUMNP)
 2500 FORMAT(I5,5X,3F10.3)
C*************************************************************************
C        READ AND PRINT OF ELEMENT PROPERTIES
C*************************************************************************
 2410 WRITE(6,2003)
      N=0
  103 READ(NF,1002) M,(IX(M,I),I=1,5),PLTM(M),MOD,NLIMIT,MPLTM,PLTINC
      WRITE(7,1002)M,(IX(M,I),I=1,5),PLTM(M),MOD,NLIMIT,MPLTM,
     1 PLTINC
      IF (MOD .NE. 0) WRITE(6,2095) MOD,NLIMIT,MPLTM,PLTINC
  104 N=N+1
      IF (M-N) 107,107,105
  105 IX(N,1)=IX(N-1,1)+1
      IX(N,2)=IX(N-1,2)+1
      IX(N,3)=IX(N-1,3)+1
      IX(N,4)=IX(N-1,4)+1
      IX(N,5)=IX(N-1,5)
      PLTM(N)=PLTM(N-1)
      GO TO 107
  106 IF(N.EQ.NLIMIT) GO TO 108
      N=N+1
      N1=N-MOD
      N2=N1-MOD
      IF((N1.GT.0).AND.(N2.GT.0)) GO TO 1107
      WRITE (6,2130)
      CALL EXIT
 1107 DO 2107 I=1,4
 2107 IX(N,I)=2*IX(N1,I)-IX(N2,I)
      IX(N,5)=IX(N-1,5)
  107 WRITE (6,2004) N,(IX(N,I),I=1,5),PLTM(N)
      IF(MOD.EQ.0) GO TO 6107
      IF(M.NE.N) GO TO 106
      II=N-1
      KK=NLIMIT-MPLTM
      DO 5107 I=II ,KK,MPLTM
      L=I
      DO 4107 J=1,MPLTM
      L=L+1
 4107 PLTM(L+1)=PLTM(L)
 5107 PLTM(L+1)=PLTM(L+1)+PLTINC
      GO TO 106
 6107 IF(M-N) 108,108,104
  108 IF (NUMEL-N) 109,109,103
  109 CONTINUE
      DO 110 I=1,NUMEL
  110 PLTM(I)=PLTM(I)*24.
C
      DO 115 N=1,150
      TMC(N)=0.0
```

```
  115 TMP(N)=0.0
      SIG1=0.
      SIG2=0.
      SIG3=0.
      IF(NTAPE11.EQ.0)GO TO 3010
      WRITE(11)(M,(IX(M,I),I=1,5),SIG1,SIG2,SIG3,M=1,NUMEL)
 3010 IF(NELCARD.EQ.0)GO TO 2450
      PUNCH 2510,(M,(IX(M,I),I=1,5),M=1,NUMEL)
 2510 FORMAT(6I5)
 3030 RETURN
C***********************************************************************
C     READ AND PRINT MATERIAL PROPERTIES AND ENVIRONMENT TEMP
C***********************************************************************
 2450 IF(NOCARD.EQ.1)GO TO 3030
      DO 120 N=1,NUMMAT
      READ(NF,1050)MT,XCOND(MT),SPHT(MT),DENS(MT),HSTOP(MT)
      WRITE(7,1050)MT,XCOND(MT),SPHT(MT),DENS(MT),HSTOP(MT)
      WRITE(6,2018) MT
      WRITE(6,2006) MT,XCOND(MT),SPHT(MT),DENS(MT),HSTOP(MT)
      HSTOP(MT)=HSTOP(MT)*24.
      WRITE(6,2007)
      READ(NF,1008) ((QX(I,J,MT),J=1,2),I=1,NUMQC)
      WRITE(6,2008) ((QX(I,J,MT),J=1,2),I=1,NUMQC)
      WRITE(7,1008)((QX(I,J,MT),J=1,2),I=1,NUMQC)
      DO 118 I=1,NUMQC
  118 QX(I,1,MT)=QX(I,1,MT)*24.
  120 CONTINUE
      IF(NUMET1 .EQ. 0) GO TO 121
      IET=1
      READ(NF,1008) ((ET(I,J,1),J=1,2),I=1,NUMET1)
      WRITE(7,1008)((ET(I,J,1),J=1,2),I=1,NUMET1)
      WRITE(6,2012) IET,((ET(I,J,1),J=1,2),I=1,NUMET1)
      DO 1120 I=1,NUMET1
 1120 ET(I,1,1)=ET(I,1,1)*24.
  121 IF(NUMET2 .EQ. 0) GO TO 122
      IET=2
      READ(NF,1008) ((ET(I,J,2),J=1,2),I=1,NUMET2)
      WRITE(7,1008)((ET(I,J,2),J=1,2),I=1,NUMET2)
      WRITE(6,2012) IET,((ET(I,J,2),J=1,2),I=1,NUMET2)
      DO 1121 I=1,NUMET2
 1121 ET(I,1,2)=ET(I,1,2)*24.
  122 IF(NUMET3 .EQ. 0) GO TO 125
      IET=3
      READ(NF,1008) ((ET(I,J,3),J=1,2),I=1,NUMET3)
      WRITE(7,1008)((ET(I,J,3),J=1,2),I=1,NUMET3)
      WRITE(6,2012) IET,((ET(I,J,3),J=1,2),I=1,NUMET3)
      DO 123 I=1,NUMET3
  123 ET(I,1,3)=ET(I,1,3)*24.
C     FOR EACH INTERVAL OF TIME--SEVERAL TIME STEPS
C***********************************************************************
  125 CONTINUE
      NCBH=0
```

```
      NEPH=0
      TIMESTIME=24.
      MCOUNT=0
      DO 130 N=1,NUMNP
  130 T(N)=0.0
      IF(ICARDS.EQ.0) GO TO 138
      KCARD =ICARDS/5
      KZ = ICARDS- KCARD*5
      IF(KZ .NE. 0) KCARD=KCARD+1
      KC = 5
      DO 135 I=1,KCARD
      IF((I .EQ. KCARD) .AND. (KZ .NE. 0)) KC=KZ
      READ(NF,1035) (IR(N),TR(N),N=1,KC)
      WRITE(7,1035)(IR(N),TR(N),N=1,KC)
      DO 133 J=1,5
      K = IR(J)
  133 T(K) = TR(J)
  135 CONTINUE
 1035 FORMAT (5(I5,F10.5))
  138 IF(NNODE .EQ.0) GO TO 149
      READ(NF,1010) (NODE(I),I=1,NNODE)
      WRITE(7,1010)(NODE(I),I=1,NNODE)
      READ(NF,1010) (LIFT(I),I=1,NNODE)
      WRITE(7,1010)(LIFT(I),I=1,NNODE)
      WRITE(6,1030) (NODE(I),I=1,NNODE)
      WRITE(6,1031) (LIFT(I),I=1,NNODE)
      IF (IPUNCH .NE. 0) WRITE (6,2035) IPUNCH
      IPUNCH = IPUNCH * 24
C
C     READ AND PRINT OF LAYER PROPERTIES
C
  149 ISPAN = ISPAN+1
  150 READ(NF,999,END=997)TITLE
      WRITE(7,999)TITLE
      READ(NF,1004) NUMN,NUME,NUMCB,NUMCP,NDT,INTER,DT,PLTIME,PLACET
      WRITE(7,1004)NUMN,NUME,NUMCB,NUMCP,NDT,INTER,DT,PLTIME,PLACET
C
      IF (NUMN.GT.0) GO TO 151
      IF (NPLOT.NE.0) STOP
      RETURN
  151 CONTINUE
      WRITE(6,2032) ISPAN,TITLE
      WRITE(6,2005) NUMN,NUME,NUMCB,NUMCP,NDT,INTER,DT,PLTIME,PLACET
      PLTIME=PLTIME*24.
      IF(ISPAN.EQ.1)NELP=1
C
C     ELIMINATE ALL INSULATING ELEMENTS AND COOLING PIPES WITH REMOVAL
C     TIME LESS THAN PLACEMENT TIME AND READ ADDITIONAL ONES
C
      KN=0
      DO 155 N=1,NCBH
      IF(TMC(N).LE.PLTIME) GO TO 155
```

```
      KK=KK+1
      IC(KK)=IC(N)
      JC(KK)=JC(N)
      HC(KK)=HC(N)
      TMC(KK)=TMC(N)
      CL(KK)=CL(N)
      IETC(KK)=IETC(N)
  155 CONTINUE
      NCBL=KK+1
      NCBH=KK+NUMCB
      IF(NUMCB.EQ.0) GO TO 160
      N=NCBL
  156 READ(NF,1005) IC(N),JC(N),HC(N),TMC(N),IETC(N),IGEN
      WRITE(Z,1005)IC(N),JC(N),HC(N),TMC(N),IETC(N),IGEN
      IF(IGEN .EQ. 0) GO TO 158
      JJ=(JC(N)-IC(N))-1
      JC(N)=IC(N)+1
      DO 157 I=1,JJ
      IC(N+1)=IC(N)+1
      JC(N+1)=JC(N)+1
      HC(N+1)=HC(N)
      TMC(N+1)=TMC(N)
      IETC(N+1)=IETC(N)
  157 N=N+1
  158 N=N+1
      IF(N .LE. NCBH) GO TO 156
      WRITE(6,2013) (IC(N),JC(N),HC(N),TMC(N),IETC(N),N=NCBL  ,NCBH)
      DO 159 N=NCBL,NCBH
  159 TMC(N)=TMC(N)*24.
  160 KK=0
      DO 165 N=1,NCPH
      IF(TMP(N).LE.PLTIME) GO TO 165
      KK=KK+1
      IP(KK)=IP(N)
      HP(KK)=HP(N)
      TP(KK)=TP(N)
      TMP(KK)=TMP(N)
  165 CONTINUE
      NCPL=KK+1
      NCPH=KK+NUMCP
      IF(NUMCP.EQ.0) GO TO 170
      N=NCPL
  166 READ(NF,1006) IP(N),HP(N),TP(N),TMP(N),J,INC
      WRITE(Z,1006)IP(N),HP(N),TP(N),TMP(N),J,INC
      N=N+1
      IF(N .GT. NCPH) GO TO 168
      IF(INC .EQ. 0) GO TO 166
  167 IP(N)=IP(N-1)+INC
      HP(N)=HP(N-1)
      TP(N)=TP(N-1)
      TMP(N)=TMP(N-1)
      N=N+1
```

```
      IF(IP(N-1) .LT. J) GO TO 167
      IF(N .LE. NCPH) GO TO 166
  168 WRITE(6,2014) (IP(N),HP(N),TP(N),TMP(N),N,N=NCPL,NCPH)
      DO 169 N=NCPL,NCPH
  169 TMP(N)=TMR(N)*24.
C
C     CHECK INCONSISTENCY OF LIFT INFORMATION AND REMOVAL OF INSULATING
C     ELEMENTS AND/OR COOLING PIPES
C
  170 KK=0
      YY=DT*FLOAT(NDT)
      IF(NCBH.EQ.0) GO TO 201
      DO 200 N=1,NCBH
      XX=TMB(N)-PLTIME
      IF(XX.LT.YY) KK=1
  200 CONTINUE
  201 IF(NCPH.EQ.0) GO TO 208
      DO 205 N=1,NCPH
      XX=TMP(N)-PLTIME
      IF(XX.LT.YY) KK=1
  205 CONTINUE
  208 IF(KK.NE.0) WRITE(6,2019)
C
C     SET ALL NEW NODES TO PLACEMENT TEMPERATURE AND CONTACT SURFACE AT
C     AVERAGE TEMPERATURES
C
      DO 210 I=1,NUMN
      B(I)=0.0
  210 Q(I)=0.0
      DO 220 N=1,NUME
      IF(PLTM(N).GT.PLTIME) GO TO 220
      DO 215 I=1,4
      II=IX(N,I)
      IF(PLTM(N).EQ.PLTIME) B(II)=B(II)+PLACET
      IF(PLTM(N).LT.PLTIME) B(II)=B(II)+T(II)
  215 Q(II)=Q(II)+1.0
  220 CONTINUE
      DO 230 N=1,NUMN
      IF(Q(N).EQ.0.0) GO TO 230
      T(N)=B(N)/Q(N)
  230 CONTINUE
C
      CALL LAYER
      IF(TEMPMAX.GT.PEAKTEMP)GO TO 2700
      TEMPMAX=PEAKTEMP
      PDAY=PEAKDAY
      NPEAKNDE=NODEPEAK
 2700 GO TO 149
C
C     FORMAT STATEMENTS
C
  997 WRITE(6,998)
```

```
  998 FORMAT("END OF FILE")
      STOP
  999 FORMAT(16A4)
 1000 FORMAT (8I5,F5.0,3I5,3F5.0,I2,I3)
 1001 FORMAT(I5,I5,3F10.0,4I5)
 1050 FORMAT(I5,5X,4F10.0)
 1002 FORMAT (6I5,F10.0,3I5,F5.0)
 1003 FORMAT (I10,4F10.0)
 1004 FORMAT(6I5,3F10.0)
 1005 FORMAT(2I5,2F10.0,2I5)
 1006 FORMAT(I5,5X,3F10.0,2I5)
 1008 FORMAT(2F10.0)
 1010 FORMAT(16I5)
 1030 FORMAT('0NODES FOR EXTRA OUTPUT'/(24I5))
 1031 FORMAT(' COLUMN HEADINGS FOR EXTRA OUTPUT'/(24I5))
 2000 FORMAT ('1',    5X,16A4//25H0NUMBER OF NODAL POINTS--,I4/
     1 25H NUMBER OF ELEMENTS------ I4 /25H NUMBER OF MATERIALS----- I4/
     2 25H NUMBER OF QB CARDS------ I4 /
     3 (25H NO OF EXT TEMP CARDS---- I4))
 2001 FORMAT (10H0 N.P. NO. 14X,1HX,14X,1HY,11X,4HTEMP)
 2002 FORMAT (1I10,3E15.6)
 2003 FORMAT (51H0   N     I     J     K     L  MATERIAL  PLACEMENT TIME)
 2004 FORMAT (5I5,I10,F16.4)
 2005 FORMAT (1H0 / 25H0NUMBER OF NODAL POINTS-- I4/
     1 25H NUMBER OF ELEMENTS------ I4 / 25H NUMBER OF CONVECTION BC-I4/
     2 25H NUMBER OF COOLING PIPE-- I4 / 25H NUMBER OF INCREMENTS----I4/
     3 25H OUTPUT INTERVAL--------- I4 / 20H TIME INTERVAL------ F10.3/
     4 25H BEGINNING TIME---------- F8.2/25H PLACEMENT TEMPERATURE---
     5 F8.2)
 2006 FORMAT(6H0    M,11X,4HCOND,11X,4HSPHT,11X,4HDENS ,4X,26HTIME HEAT
     1GENERATION STOPS/(I6,3F15.6,F30.5))
 2007 FORMAT(43H0ADIABATIC TEMPERATURE RISE OF THE MATERIAL/ 9H0    TIME
     1  9X,11HTEMPERATURE)
 2008 FORMAT(F9.2,E15.6)
 2009 FORMAT (4H0  M 14X 1HK 14X 1HC 14X 1HD 14X 1HQ/ (I4,4E15.6))
 2011 FORMAT (27H1TWO DIMENSIONAL PLANE BODY )
 2012 FORMAT(27H0TEMPERATURE OF ENVIRONMENT,I2 / 7H0  TIME,4X,
     1  11HTEMPERATURE/(F9.2,E15.6))
 2013 FORMAT(20H0INSULATING ELEMENTS//4H   I,5H   J,14X,1HH,41H   TIME R
     1EMOVED  ENVIRON.  ARRAY POSITION /(2I5,2F15.6,I5,I10))
 2014 FORMAT(25H0DETAILS OF COOLING PIPES//6H   I,14X,1HH,16H    TEMPERA
     1TURE ,30H  TIME REMOVED  ARRAY POSITION/(I5,3F15.6,I10))
 2018 FORMAT(1H0,4X,15HMATERIAL TYPE =,I3)
 2019 FORMAT(35H0****  ERROR MESSAGE   WARNING ONLY/1X,76HNEW LIFT DATA
     1IS NOT SUPPLIED EVEN THOUGH A CHANGE WAS OCCURED IN INSULATING/
     2 /X,52HELEMENTS AND/OR COOLING PIPES, CALCULATION PROCEEDS)
 2020 FORMAT (10H0CARD NO. I4, 13H OUT OF ORDER )
 2021 FORMAT (13H0BAD CARD NO. I4)
 2032 FORMAT(     '1SPAN = ',I5/16A4)
 2035 FORMAT ('0TEMPERATURES PUNCHED AT DAY =',I5,'  FOR RESTART RUN')
 2090 FORMAT(1H+,60X,5H MOD=,I3,3X,6H NLIM=,I4,3X,6H FACX=,F10.5,
     16H FACY=,F10.5)
```

```
 2095 FORMAT(1+',60X,' MOD=',I5,' NLIMIT=',I5,' MPLTM=',I5,' PLTINC=',
     1F9.2)
 2130 FORMAT(42H0INSUFFICIENT INFORMATION TO GENERATE MESH)
      END
      SUBROUTINE LAYER
      PARAMETER MAXN=580,MAXBW=9,MXE=480
      COMMON NODAY,NUMEL,NCBH,NCPH,NUMMAT,NDT,INTER,DT,TIME,NUMNP,NUME,
     1  NUMOC,PLTIME,B(MAXN),X(MAXN),Y(MAXN),T(MAXN),D(MAXN),TT(MAXN),
     2  IX(MXE,5),PLTM(MXE),VOL(MXE),HED(16),LM(5),E(3,3),KX(4),S(5,5),
     3  XCOND(10),SPHT(10),DENS(10),QX(35,2,10),USTOR(10),ET(100,2,3),
     4  IC(210),JC(210),HC(210),THC(210),CL(210),ISPAN,PLACET,NELP,
     5  IP(210),HP(210),TP(210),THP(210),IETC(210),NE,TEMPMAX,PDAY,
     6 PEAKDAY,NODEPEAK,PEAKTEMP,NPEAKNDE,TSF(MXE)
      COMMON /OUTPUT/ NNODE,MCOUNT,NODE(30),LIFT(30),TITLE(16),IPUNCH,
     1 SOLC(3),NPLOT,NDATE(2)
      COMMON/SYMARG/NUMN,MBAND,A(MAXN,MAXBW),Q(MAXN)
      COMMON/NPRIV/NTAPE11
      DIMENSION TNODE(30)
C
C**********************************************************************
C     FORM CONDUCTIVITY MATRIX FOR COMPLETE BODY
C**********************************************************************
      DO 130 I=1,NUMN
      D(I)=0.0
      B(I)=0.0
      Q(I)=0.0
      DO 130 J=1,MAXBW
  130 A(I,J)=0.0
      MBAND=0
      ISTOP=0
C
      DO 200 N=1,NUME
      IF(PLTM(N).GT.PLTIME) GO TO 200
      MTYPE=IX(N,5)
      COND=XCOND(MTYPE)
C     2. FORM ELEMENT CONDUCTIVITY MATRIX
C
      DO 150 I=1,5
      LM(I)=IX(N,I)
      DO 150 J=1,5
  150 S(I,J)=0.0
C
      I=LM(1)
      J=LM(2)
      K=LM(3)
      L=LM(4)
      LM(5)=I
C
      XX=(X(I)+X(J)+X(K)+X(L))/4.
      YY=(Y(I)+Y(J)+Y(K)+Y(L))/4.
      VOL(N)=0.0
C
```

```
      DO 152 K=1,4
C
      I=LM(K)
      J=LM(K+1)
      IF (I-J) 135,152,135
  135 AJ=X(J)-X(I)
      AK=XX-X(I)
      BJ=Y(J)-Y(I)
      BK=YY-Y(I)
      C=BJ-BK
      DX=AK-AJ
C
      XLAM=AJ*BK-AK*BJ
      IF(XLAM.GT.0.0) GO TO 136
      ISTOP=1
      WRITE(6,2003) N
  136 VOL(N)=VOL(N)+XLAM*0.5
      COMM=0.5*COND/XLAM
C
      E(1,1)=C**2+DX**2
      E(1,2)=BK*C-AK*DX
      E(1,3)=-BJ*C+AJ*DX
      E(2,1)=E(1,2)
      E(2,2)=BK**2+AK**2
      E(2,3)=-BJ*BK-AJ*AK
      E(3,1)=E(1,3)
      E(3,2)=E(2,3)
      E(3,3)=BJ**2+AJ**2
C
      KX(1)=K
      KX(2)=K+1
      IF (K-4) 145,140,145
  140 KX(2)=1
  145 KX(3)=5
C
      DO 151 I=1,3
      II=KX(I)
      DO 151 J=1,3
      JJ=KX(J)
  151 S(II,JJ)=S(II,JJ)+E(I,J)*COMM
C
  152 CONTINUE
C
      DO 155 I=1,4
      DO 155 J=1,4
  155 S(I,J)=S(I,J)-S(I,5)*S(J,5)/S(5,5)
C
C     3. ADD ELEMENT CONDUCTIVITY TO COMPLETE CONDUCTIVITY MATRIX
C
      VOL(N)=VOL(N)*SPHT(MTYPE)*DENS(MTYPE)*0.25
      DO 175 L=1,4
      I=LM(L)
```

```
      D(I)=D(I)+VOL(N)
      DO 175 M=1,4
      J=LM(M)-I+1
      IF (MAXBW-J) 157,158,158
  157 WRITE (6,2002) N
      GO TO 200
  158 IF(MBAND-J) 160,165,165
  160 MBAND=J
  165 IF(J) 175,175,170
  170 A(I,J)=A(I,J)+S(L,M)
  175 CONTINUE
C
  200 CONTINUE
      IF(ISTOP.EQ.1) STOP
C*********************************************************************
C     BOUNDARY CONDITIONS
C*********************************************************************
      IF(NCBH.EQ.0) GO TO 220
      DO 215 N=1,NCBH
      I=IC(N)
      J=JC(N)
      XL=SQRT((X(J)-X(I))**2+(Y(J)-Y(I))**2)
      H=HC(N)*XL*0.25
      A(I,1)=A(I,1)+H
      A(J,1)=A(J,1)+H
      K=J-I+1
      IF (K) 212,212,210
  210 A(I,K)=A(I,K)+H
      GO TO 215
  212 K=I-J+1
      A(J,K)=A(J,K)+H
  215 CL(N)=XL
  220 CONTINUE
C
C     COOLING PIPES
C
      IF(NCPH.EQ.0) GO TO 225
      DO 224 N=1,NCPH
      I=IP(N)
      A(I,1)=A(I,1)+HP(N)
  224 B(I)=B(I)+HP(N)*TP(N)
  225 CONTINUE
C
C     2. TEMPERATURE BOUNDARY CONDITIONS
C
      DO 300 N=1,NUMN
C
      IF(TT(N).EQ.0.0) GO TO 300
      DO 250 M=2,MBAND
      K=N-M+1
      IF(K) 235,235,230
  230 B(K)=B(K)-A(K,M)*TT(N)
```

```
      A(N,M)=0.0
  235 L=N+M-1
      IF(NUMN-L) 245,240,240
  240 B(L)=B(L)-A(N,M)*TT(N)
  245 A(N,M)=0.0
  250 CONTINUE
      A(N,1)=1.0
      T(N)=TT(N)
  300 CONTINUE
C
C**************************************************************************
C     SOLVE FOR NODAL POINT TEMPERATURES
C**************************************************************************
C     FORM EFFECTIVE CONDUCTIVITY MATRIX FOR TIME INCREMENT
C
      DT2=1.0/DT
      DO 320 N=1,NUMN
      IF(A(N,1).EQ.0.0) A(N,1)=1.0
      IF(TT(N).NE.0.0) GO TO 320
      D(N)=DT2*D(N)
      A(N,1)=A(N,1)+D(N)
  320 CONTINUE
      CALL SYMSOL(1)
C
C     SET UP FLAGS FOR STRESS FREE TEMP OUTPUT
C
      LL=0
      NCFLG=1
      NCYL=0
C
C     IS THIS A FAKE LIFT,IE,FOR PIPE REMOVAL IN MIDLIFT?
C
      IF(NELP.GT.NUME)GO TO 710
      SFT=8?
      KDT=SFT/DT
      IF(DT.GT.SFT)GO TO 702
      IF(DT.EQ.SFT)GO TO 701
      DDT=KDT
      DDT1=SFT/DT
      DEL=DDT1-DDT
      IF(DEL.GE.0.5)GO TO 702
      IF(DEL.EQ.0.)GO TO 701
  700 NCYL=KDT
      NCFLG=2
      GO TO 705
  701 NCYL=KDT
      NCFLG=1
      GO TO 705
  702 NCYL=KDT+1
      NCFLG=3
  705 CONTINUE
C
```

```
C     CALC TEMP AT END OF EACH TIME INCREMENT
C
  710 DO 600 KK=1,NDT
C
C     DETERMINATION OF HEAT GENERATION
C
      DO 395 N=1,NUME
      IF(PLTM(N).GT.TIME) GO TO 395
      MTYPE=IX(N,5)
      TX=TIME-PLTM(N)
      IF(TX.GE.HSTOP(MTYPE)) GO TC 395
      DO 385 L=2,NUMQC
      XZ=QX(L,1,MTYPE)-TX
      IF(XZ.GT.0.0) GO TO 386
  385 CONTINUE
  386 DIFF=QX(L,1,MTYPE)-QX(L-1,1,MTYPE)
      GRAD=(QX(L,2,MTYPE)-QX(L-1,2,MTYPE))/DIFF
      QQ=GRAD*VOL(N)
      DO 390 I=1,4
      II=IX(N,I)
  390 Q(II)=Q(II)+QQ
  395 CONTINUE
C
C     CONVECTION BOUNDARY CONDITICN
C
      IF(NCBH.EQ.0) GO TO 410
      DO 405 M=1,NCBH
      I=IC(M)
      J=JC(M)
      II=IETG(M)
      DO 400 N=1,100
      IJ=N
      XZ=ET(N,1,II)-TIME
      IF(XZ) 400,400,401
  400 CONTINUE
  401 DIFF=ET(IJ,1,II)-ET(IJ-1,1,II)
      XYZ=XZ/DIFF
      XXX=ET(IJ,2,II)-ET(IJ-1,2,II)
      TEMP=ET(IJ,2,II)-XXX * XYZ
      TEMP=TEMP*SOLC(II)
      XZ=HC(M)*CL(M)*TEMP*0.5
      Q(I)=Q(I)+XZ
  405 Q(J)=Q(J)+XZ
  410 CONTINUE
C
C      1. CALCULATE EFFECTIVE LOAD MATRIX
C
      DO 450 I=1,NUMN
      Q(I)=Q(I)*B(I)*D(I)*T(I)
      IF(TT(I).NE.0.0) Q(I)=TT(I)
  450 CONTINUE
C
```

```
C      2. SOLVE FOR TEMPERATURES
C
       CALL SYMBOL(2)
C
       DO 500 I=1,NUMN
       T(I)=Q(I)
  500  Q(I)=0.0
C
       TIME =TIME+DT
       DAY=TIME/24.
       JJJ = TIME
C
C      PUNCH CARDS FOR RESTART RUN
C
       IF(JJJ.NE.IPUNCH) GO TO 510
       WRITE(07,2006) (I,T(I),I=1,NUMN)
       IF(NCBH .EQ. 0) GO TO 502
       DO 501 N=1,NCBH
       XTMC = TMC(N)/24.0
  501  WRITE(07,2007) IC(N),JC(N),HC(N),XTMC,IETC(N)
  502  IF(NCPH .EQ. 0) GO TO 510
       DO 503 N=1,NCPH
       XTMP = TMP(N)/24.0
  503  WRITE(07,2008) IP(N),HP(N),TP(N),XTMP
 2006  FORMAT (5(I5,F10.5))
 2007  FORMAT (2I5,F10.5,F10.2,I5)
 2008  FORMAT (I5,5X,F10.5,F10.2,F10.2)
  510  IF(NNODE .EQ. 0) GO TO 554
       IF(AMOD(DAY,1.0) .NE. 0.0) GO TC 554
       IF(NODE(1) .GT. NUMN) GO TO 554
       KOUT=1
  551  DO 552 I=1,NNODE
       TNODE(I) = 0.0
       II=NODE(I)
       IF(II .GT. NUMN) GO TO 800
       KOUT=I
  552  TNODE(I) = T(II)
  800  MCOUNT = MCOUNT-1
       IF(MCOUNT .GT. 0) GO TO 553
       MCOUNT = 40
       WRITE(6,3000) NDATE,HED,(LIFT(I),I=1,NNODE)
 3000  FORMAT ('1',2A4,5X,16A4/'0 DAY              IDENT NUMBER'/7X,24I5/)
  553  WRITE(6,2030) DAY,(TNODE(I),I=1,KOUT)
       IF(NPLOT.NE.0) GO TO 554
       NODAY=NODAY+1
 2030  FORMAT(F7.2,(24F5.1))
  554  CONTINUE
       LL=LL+1
       IF(ISPAN.GT.1)GO TO 770
       IF(KK.NE.NOYL)GO TO 755
       WRITE(08,780)
  780  FORMAT(" SPAN 1 VALUES-POSSIBLY FCUNDATION")
```

```
  770 IF(KM.NE.NCYL)GO TO 755
      DO 752 I=NELP,NUME
      J1=IX(I,1)
      J2=IX(I,2)
      J3=IX(I,3)
      J4=IX(I,4)
      IF(J3.EQ.J4)GO TO 750
      TSF(I)=(T(J1)+T(J2)+T(J3)+T(J4))/4.
      GO TO 751
  750 TSF(I)=(T(J1)+T(J2)+T(J3))/3.
  751 IF(NCFLG.EQ.1)GO TO 752
      TSF(I)=(SFT*(TSF(I)-PLACET)+DT*NCYL*PLACET)/(DT*NCYL)
  752 CONTINUE
      WRITE(08,760)ISPAN,SFT,DT,DET1,PLACET,DAY,NCYL,KDT
  760 FORMAT(///" SPAN=-------",I4,/" SFT-HOURS=--",F10.3,/
     1" DT-HOURS---=",F10.3,/" SFT/DT-------",F10.3,/
     2" PLACE TEMP=",F10.3,/" DAYS--------",F10.3,/
     3" NCYL------=",I4,/" KDT-COUNT--",I4//)
      WRITE(08,761)(I,TSF(I),I=NELP,NUME)
  761 FORMAT(5(I5,F10.3))
      WRITE(09,767)(I,TSF(I),I=NELP,NUME)
  767 FORMAT(2X,I8,F10.3)
  755 CONTINUE
      IF(LL-INTER) 600,550,550
  550 WRITE (6,2001) DAY,(N,T(N),N=1,NUMN)
      IF(NTAPE11.EQ.0)GO TO 3920
      WRITE(11,2004) DAY,(N,T(N),N=1,NUMN)
 3920 LL=0
      PEAKTEMP=0.
      DO 825 N=1,NUMN
      IF(T(N).GT.PEAKTEMP)GO TO 826
      GO TO 825
  826 PEAKTEMP=T(N)
      NODEPEAK=N
      PEAKDAY=DAY
  825 CONTINUE
      WRITE(6,2600)DAY,PEAKTEMP,NODEPEAK
C
  600 CONTINUE
      NELP=NUME+1
      RETURN
C*********************
C
 2001 FORMAT(///8H TIME = ,F8.2,6H  DAYS/(10(I5,F8.2)))
 2002 FORMAT (23H BAND TOO LARGE-EL,NO,    I5)
 2003 FORMAT(34H ZERO OR NEGATIVE AREA  ELEMENT NO,I5)
 2004 FORMAT(8H TIME = ,F8.2,6H  DAYS,100X,1H1/(7(I6,F7.1),35X,1H1))
 2600 FORMAT(/"*******PEAK TEMPERATURE THIS CALCULATION",
     1 "*******",//" THE PEAK TEMPERATURE FOR THE",F5.1," DAY ",
     2 "= ",F6.2," DEGREES AT NODE= ",I4)
C
      END
```

```
      SUBROUTINE SYMSOL (KKK)
      PARAMETER MAXN=580,MAXBW=9,MXE=400
C
      COMMON /SYMARG/ NN,MM,A(MAXN,MAXBW),B(MAXN)
C
      GO TO (1000,2000),KKK
C
C     REDUCE MATRIX
C
 1000 DO 280 N=1,NN
      DO 260 L=2,MM
      C=A(N,L)/A(N,1)
      I = N+L-1
      IF(NN-I) 260,240,240
  240 J=0
      DO 250 K=L,MM
      J=J+1
  250 A(I,J)=A(I,J)-C*A(N,K)
  260 A(N,L)=C
  280 CONTINUE
      GO TO 500
C
C     REDUCE VECTOR
C
 2000 DO 290 N=1,NN
      DO 285 L=2,MM
      I=N+L-1
      IF(NN-I) 290,285,285
  285 B(I)=B(I)-A(N,L)*B(N)
  290 B(N)=B(N)/A(N,1)
C     BACK SUBSTITUTION
C
      N=NN
  300 N = N-1
      IF(N) 350,500,350
  350 DO 400 K=2,MM
      L = N+K-1
      IF(NN-L) 400,370,370
  370 B(N) = B(N) - A(N,K) * B(L)
  400 CONTINUE
      GO TO 300
C
  500 RETURN
C
      END
      SUBROUTINE TPLOT
      RETURN
      END
$      EXECUTE DUMP
$      LIMITS  40,33K,,25000
$      FILE    07,D1S,8L
$      FILE    08,D2S,6L
```

```
3279T 01  08-11-78   16.456

$       PRMFL   09,R/W,L,ROCC46/SFCUTDW1                              00008650
        TAPE9   11,A1D,,,,DWORSH-WES#1                                00008655
        MSG2    SAVE 11,BOMBICH,ROCC46,DWORSH-WES#1                   00008656
$       DATA    20                                                    00008680
$       BREAK                                                         00008700
$       CONVER                                                        00008710
$       LIMITS  ,,,2000                                               00008720
$       SYSOUT  OT                                                    00008730
$       FILE    IN,D1R                                                00008740
$       BREAK                                                         00008741
$       CONVER                                                        00008742
$       LIMITS  ,,,1000                                               00008743
$       SYSOUT  OT                                                    00008744
$       FILE    IN,D2R                                                00008750
$       ENDJOB                                                        00008760
```

APPENDIX B: TWO-DIMENSIONAL THERMAL STRESS/STRAIN CALCULATION PROGRAM (WES VERSION)

```
$     IDENT   ROCC46,CAMPBELL
$     MSG3    062878/1700
$     OPTION  FORTRAN
$     FORTY   XREF,MAP,DECK
$     LIMITS  ,33K,,6000
$     FILE    C*,X3S,1L,NEW,BSTBESDW
C     STRESSV-WITH VARIABLE TIME AND STRAIN CAP INPUT
C****COPY AS OF 27 MARCH 75,INCL STRAIN CAP,, SPECIFIC ANALYSIS TIMES
C     ARBITRARY TWO-DIMENSIONAL STRESS STRUCTURE INCLUDING INCREMENTAL
C     CONSTRUCTION, MCHENRY CREEP, RESIDUAL STRESSES, THERMAL STRESSBS,
C     VARYING PRESSURE BOUNDARY CONDITIONS, AND BIMODULAR MATERIAL
C     PROPERTIES.
C
C     MXN=MAXIMUM NO. OF NODES
C     MXE=MAXIMUMUM NO. OF ELEMENTS
C     MN2=MAX NODES * 2
C
      PARAMETER MXN=576,MXE=475,MN2=MXN*2
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
      COMMON /MATARG/ E(30,6,8),RO(8),EB(8),HED(15),CIC(20,4,8),
     1CC(4,8),NCREEP(8),SC(30,2,8),NSC
      COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
      COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
      COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
      COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
      COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
     1 F(3,3)
      CHARACTER READMODE*6,DASH*6,OVER*6
      DIMENSION FF(MN2),IBUF(380),TSAVE(MXE)
      SFTIM=8.
      DASH=6H COMP
      OVER=6H >1K%
      NF=20
      WRITE(7,4100)
      READMODE=6H
C****READ AND PRINT OF CONTROL INFORMATION AND MATEREIAL PROP.
C*****************************************************************
   50 READ(NF,1000,END=5000)HED
C**READ MODE OF INPUT- "TAPE" OR "CARD" FOR NODES,ELEMENTS, &TEMPS.
      READ(NF,998)READMODE,NEXTRA
      READ(NF,999)NUMNP,NUMEL,NUMMAT,NLAY,ISC,NANALT,TI,T1
      WRITE(6,1009)
      WRITE (6,2000) HED,NUMNP,NUMEL,NUMMAT,NLAY,ISC,TI,NANALT
      WRITE(7,2000)HED,NUMNP,NUMEL,NUMMAT,NLAY,ISC,TI,NANALT
   56 DO 59 M=1,NUMMAT
      READ(NF,1001) MTYPE,NUMTC,NSC,NCREEP(MTYPE),RO(MTYPE)
```

```
      WRITE (6,2011) MTYPE,NUMTC,NCREEP(MTYPE),RO(MTYPE)
      WRITE(6,2051)NSC
      READ(NF,1005) ((E(I,J,MTYPE),J=1,6),I=1,NUMTC)
      WRITE (6,2010) ((E(I,J,MTYPE),J=1,6),I=1,NUMTC)
      DO 58 I=NUMTC,30
      DO 58 J=1,6
   58 E(I,J,MTYPE)=E(NUMTC,J,MTYPE)
      IF(ISC.EQ.0)GO TO 910
      READ(NF,1008)((SC(I,J,MTYPE),J=1,2),I=1,NSC)
      WRITE(6,2052)((SC(I,J,MTYPE),J=1,2),I=1,NSC)
      DO 75 I=NSC,30
      DO 75 J=1,2
   75 SC(I,J,MTYPE)=SC(NSC,J,MTYPE)
  910 CONTINUE
      IF (NCREEP(MTYPE)) 54,59,54
   54 NCR=NCREEP(MTYPE)
      READ(NF,1003)  (TTT(I),(CIC(I,J,MTYPE),J=1,4),I=1,NCR)
      WRITE (6,2013) MTYPE, (TTT(I),(CIC(I,J,MTYPE),J=1,4),I=1,NCR)
      READ(NF,1005) (CC(I,MTYPE),I=1,4)
      WRITE (6,2014) (CC(I,MTYPE),I=1,4)
   59 CONTINUE
C*****READ AND PRINT NODAL LOAD/DISPLACEMENT BOUNDARY COND.***
      WRITE(6,2004)
      L=1
 3006 READ(NF,3000)N,CODE(N),UR(N),UZ(N)
      IF(N.EQ.1)GO TO 3006
 3005 L=L+1
      IF(N-L)3002,3001,3004
 3004 CODE(L)=CODE(L-1)
      UR(L)=0.
      UZ(L)=0.
      GO TO 3005
 3002 WRITE(6,2017)N
      CALL EXIT
 3001 IF(L.EQ.NUMNP)GO TO 3008
      GO TO 3006
C*****READ NODAL POINT DATA FROM TAPE/DISK AND PRINT*********
 3008 L=0
      IF(READMODE.EQ.6HTAPE  )GO TO 905
      READ(NF,4000)(M,R(N),Z(N),N=1,NUMNP)
      GO TO 906
  905 READ(4)(M,R(N),Z(N),N=1,NUMNP)
  906 CONTINUE
      WRITE(6,2002)(K,CODE(K),R(K),Z(K),UR(K),UZ(K),K=1,NUMNP)
      WRITE(3)(K,CODE(K),R(K),Z(K),UR(K),UZ(K),K=1,NUMNP)
      WRITE (6,2001)
C*****READ ELEMENT DATA FROM TAPE OR CARDS AND PRINT*********
      N=0
      IF(READMODE.EQ.6HTAPE  )GO TO 908
      READ(NF,4001)(M,(IX(N,I),I=1,5),(SIG(N,I),I=1,3),N=1,NUMEL)
      GO TO 909
  908 READ(4)(N,(IX(M,I),I=1,5),(SIG(M,I),I=1,3),M=1,NUMEL)
```

```
  909 CONTINUE
      WRITE(6,2003)(N,(IX(N,I),I=1,5),(SIG(N,I),I=1,3),N=1,NUMEL)
      WRITE(3)(N,(IX(N,I),I=1,5),(SIG(N,I),I=1,3),N=1,NUMEL)
      J=0
      DO 340 N=1,NUMEL
      DO 340 I=1,4
      DO 325 L=1,4
      KK=IABS(IX(N,I)-IX(N,L))
      IF (KK-J) 325,325,320
  320 J=KK
  325 CONTINUE
  340 CONTINUE
      MBAND=2*J+2
      NUMOL=0
      NANAL=0
      TIME=TI
      TIM=TI
      TLAST=TI
C*****READ ELEMENT STRESS FREE TEMPERATURES***********************
      L=1
 3026 READ(NF,3020)M,TOLD(M)
      IF(M.EQ.1)GO TO 3026
 3025 L=L+1
      IF(M-L)3022,3021,3024
 3024 TOLD(L)=TOLD(L-1)
      GO TO 3025
 3022 WRITE(6,3027)M
      CALL EXIT
 3021 IF(L.EQ.NUMEL)GO TO 3031
      GO TO 3026
 3031 L=0
      WRITE(6,3028)(M,TOLD(M),M=1,NUMEL)
      DO 450 N=1,NUMEL
      DE11(N)=0.
      DE12(N)=0.
      DE21(N)=0.
      DE22(N)=0.
      SIG(N,4)=0.
      SIG(N,5)=0.
      MTAG(N)=1
      IF (SIG(N,1)) 445,445,440
  440 IF (SIG(N,1)+SIG(N,2)) 441,441,442
  441 MTAG(N)=2
      GO TO 450
  442 MTAG(N)=3
  445 IF (SIG(N,2)) 450,450,448
  448 MTAG(N)=4
  450 CONTINUE
      DO 460 N=1,NUMNP
      FF(2*N-1)=0.
  460 FF(2*N)=0.
C*****READ ANALYSIS TIMES(DAYS) FOR RUN
```

```
      READ(NE,3017)(ANAL(N),N=1,NANALT)
      WRITE(6,3042)(ANAL(N),N=1,NANALT)
 3042 FORMAT(///" ANALYSIS TIMES FOR RUN(DAYS)"//,11X,18F7.1))
      NAL=1
      NCP=0
      IF(NEXTRA.EQ.1)NCP=1
      DO 870 KK=1,NUMMAT
      IF(NCREEP(KK).GT.0)NCP=1
  870 CONTINUE
  890 DTT=1.0
      NFLAG=0
      NANAL=1
C*****READ LIFT CONTROL DATA*************************************
      DO 600 LLL=1,NLAY
  550 READ(NE,1006) LAY,NUMN,NUME(LAY),NUMPC,NP,NDT,TIMLA(LAY),TIMNL
      WRITE (6,2008) LAY,NUMN,NUME(LAY),NUMPC,NP,NDT,TIMLA(LAY),TIMNL
      JFLAG=0
      NNAL=1
      NUMNL=NUME(LAY)
      IF(NFLAG.EQ.2)GO TO 951
  897 IF(NNAL.EQ.NDT.AND.NCP.EQ.1)NFLAG=1
C*****READ NODAL TEMPERATURES FROM TAPE OR CARDS*****************
  951 IF(READMODE.EQ.6HTAPE  )GO TO 901
      READ(NE,3009)TIMETAPE
      READ(NE,3007)(T(KK),KK=1,NUMN)
      GO TO 902
  901 READ(4,3040)TIMETAPE
      READ(4,3041)(T(KK),KK=1,NUMN)
  902 CONTINUE
      IF(NANAL.GT.1)GO TO 940
      IF(TIME-ANAL(NAL))943,944,943
  944 DT=TIME-0.0
      IF(TIMETAPE-TIME)941,952,941
  940 IF(NFLAG.EQ.2)GO TO 947
      IF(TIMETAPE-TIME)951,952,953
  947 IF(TIMETAPE-TIMET)951,952,953
  952 DO 871 KK=1,NUMNL
      I=IX(KK,1)
      J=IX(KK,2)
      K=IX(KK,3)
      L=IX(KK,4)
      IF(K.EQ.L)GO TO 872
      TEMPE(KK)=(T(I)+T(J)+T(K)+T(L))/4.
      GO TO 871
  872 TEMPE(KK)=(T(I)+T(J)+T(K))/3.
  871 CONTINUE
      IF(NFLAG.NE.2)GO TO 895
      DO 874 KK=1,NUMNL
  874 TSAVE(KK)=TEMPE(KK)
  895 IF(NCP.NE.1)GO TO 955
  975 DDT1=ANAL(NAL+1)-ANAL(NAL)
      IF(NFLAG.EQ.0)GO TO 896
```

```
      GO TO (960,985,964,961,963),NFLAG
  961 DO 884 KK=1,NUMNL
  884 TEMPE(KK)=TSAVE(KK)
  896 IF(DDT1.GE.1.0.AND.DDT1.LT.2)DTT=0.5
      IF(DDT1.GE.2.)DTT=1.0
      GO TO 962
  985 NEW=NUME(LAY-1)
      DO 880 KK=1,NEW
  880 TEMPE(KK)=(TSAVE(KK)-TOLD(KK))*SFTIM/24.+TOLD(KK)
      DO 881 KK=NEW+1,NUMNL
  881 TEMPE(KK)=TOLD(KK)
      GO TO 960
  964 DO 883 KK=1,NUMNL
  883 TEMPE(KK)=(TSAVE(KK)-TOLD(KK))*.5+TOLD(KK)
  960 DTT=SFTIM*.5/24.
  962 CONTINUE
      IF(NFLAG.GE.3)GO TO 310
      IF(NFLAG.EQ.0.AND.JFLAG.EQ.1)GO TO 310
  955 WRITE(6,2009)NANAL,LAY,TIMETAPE,(KK,T(KK),KK=1,NUMN)
      IF (NUMPC) 290,310,290
C*****READ PRESSURE B. C. FROM CARD OR TAPE****************************
  290 WRITE (6,2005)
      DO 300 L=1,NUMPC
      READ(NF,1004) IBC(L),JBC(L),PR(L)
  300 WRITE (6,2007) IBC(L),JBC(L),PR(L)
  310 CONTINUE
      JFLAG=0
      WRITE(6,4009)NFLAG,DTT
 4009 FORMAT(/" NFLAG=",I4," DTT=",F10.4/)
      IF(NFLAG.GT.1)GO TO 55
      WRITE(6,2025)
 2025 FORMAT(//" **NODAL DISPLACEMENTS"/)
   55 CONTINUE
      IF (NP-1) 435,435,500
  435 DO 350 N=1,NUMNL
  350 MTAG(N)=1
  500 CONTINUE
      NCOUNT=0
      DO 570 NNN=1,NP
  425 NCOUNT=NCOUNT+1
C*****FORM STIFFNESS M ATRIX*******************************************
      CALL STIFF
C*****CALCULATE NODAL DISPLACEMENTS************************************
      CALL BANSOL
      IF (NCOUNT-NP) 525,510,510
  510 DO 520 N=1,NUMN
C*****INITIALIZE DISPLACEMENTS*****************************************
      FF(2*N-1)=FF(2*N-1)+B(2*N-1)
  520 FF(2*N)=FF(2*N)+B(2*N)
      IF(NFLAG.GT.1)GO TO 525
      WRITE (6,2006) (N,FF(2*N-1),FF(2*N),N=1,NUMN)
      WRITE(3)(N,FF(2*N-1),FF(2*N),N=1,NUMN)
```

```
C*****CALCULATE STRESSES AND STRAINS**********************************
  525 CALL CREEP
  570 CONTINUE
C*****DETERMINE TIMES FOR NEXT CYCLE**********************************
      NUMOL=NUME(LAY)
      IF((NAL+1).GT.NANALT)GO TO 5000
      IF(NFLAG.GT.0)NFLAG=NFLAG+1
      IF(NFLAG.EQ.4)JFLAG=1
      IF(NFLAG.EQ.0)GO TO 965
      GO TO(967,967,967,969,970),NFLAG
  969 NFLAG=0
      DT=TLAST+1.-TIME
      TIM=TIME+DT/2.
      TIME=TLAST+1.
      TLAST=TIME
      DO 971 KK=1,NUMNL
  971 TEMPE(KK)=TSAVE(KK)
      GO TO 400
  967 DT=SPTIM/24.
      TIM=TIME+DT/2.
      TIMET=TIME+ANAL(NAL+1)-ANAL(NAL)
      TIME=TIME+DT
      IF(NFLAG.EQ.2)GO TO 898
      GO TO 975
  965 DT=ANAL(NAL+1)-ANAL(NAL)
      TIM=TIME+DT/2.
      TIME=TIME+DT
      TLAST=TIME
  898 NAL=NAL+1
      NNAL=NNAL+1
      NANAL=NANAL+1
  400 IF(NNAL.GT.NDT)GO TO 600
      IF(NNAL.EQ.1)GO TO 895
      GO TO 897
  600 CONTINUE
      GO TO 50
  941 WRITE(6,4002)TIME,TIMETAPE
 4002 FORMAT(" ABORT--FIRST ANALYSIS TIME AND TAPETIME DO NOT ",
     1"AGREE! "/" TIME---- = ",F7.2/" TIMETAPE = ",F7.2)
  943 WRITE(6,4003)TIME,ANAL(NAL)
 4003 FORMAT(" ABORT--TIMES OF FIRST ANALYSIS GIVEN BY TI AND ",
     1"ANAL(1) DO NOT AGREE!"/" TI------ = ",F7.2," DAYS"/
     2"ANAL(1)- = ",F7.2," D AYS")
      GO TO 5000
  953 WRITE(6,4004)TIME,TIMETAPE
 4004 FORMAT(" ABORT--NEXT ANALYSIS TIME CANNOT BE FOUND ON TAPE",
     1/" TIME---- = ",F7.2," DAYS"/" TIMETAPE = ",F7.2," DAYS")
      GO TO 5000
  963 WRITE(6,4006)
 4006 FORMAT(" NFLAG CANNOT = 5 AT STATEMENT 975+")
      GO TO 5000
  970 WRITE(6,4007)
```

```
4007 FORMAT(" NFLAG CANNOT = 5 AT STATEMENT 969-")
     GO TO 5000
 998 FORMAT(1X,A4,I5)
 999 FORMAT(6I5,2F10.0)
1000 FORMAT(15A4)
1001 FORMAT(4I5,F10.0)
1002 FORMAT (I5,F5.0,4F10.0)
1003 FORMAT(F10.0,4E10.3)
1004 FORMAT(2I5,F10.0)
1005 FORMAT(6F10.0)
1006 FORMAT(6I5,2F10.0)
1008 FORMAT(2F10.0)
1009 FORMAT(1H1)
2000 FORMAT (15A4/
    1 40H0 NUMBER OF NODAL POINTS------------------ I3/
    2 40H0 NUMBER OF ELEMENTS---------------------- I3/
    3 40H0 NUMBER OF DIFFERENT MATERIALS----------- I3/
    4 40H0 NUMBER OF LAYERS IN THE STRUCTURE------- I3/
    5 40H0 STRAIN CAPACITY INPUT? 1-YES, 0-NO --- I5/
    6 40H0 TIME OF FIRST ANALYSIS------------------ F10.4/
    7 40H0 TOTAL NO. OF ANALYSES REQUESTED--------- I4)
2001 FORMAT (92H1ELEMENT NO.       I      J      K      L     MATERIAL    SI
    1G1-RESIDUAL     SIG2-RESIDUAL     ANGLE  )
2002 FORMAT (I12,F12.2,2F12.3,2E24.7)
2003 FORMAT (1I13,4I6,1I12,2F17.3,F9,3)
2004 FORMAT  (97H1NODAL POINT            TYPE  X-ORDINATE  Y-ORDINATE  X LO
    1AD OR DISPLACEMENT  Y LOAD OR DISPLACEMENT )
2005 FORMAT (29H0PRESSURE BOUNDARY CONDITIONS/ 24H      I     J    PRESS
    1URE )
2006 FORMAT(5(26H N.P. DISPL-UX  DISPL-UY  )/5(I5,2F10.5,1X))
2007 FORMAT (2I6,F12.3)
2008 FORMAT (50H1 NUMBER OF LAYERS IN THE ANALYSIS-----------------=I5/
    1 50H0 NUMBER OF NODAL POINTS IN THE ANALYSIS-----------=I5/
    2 50H0 NUMBER OF ELEMENTS IN THE ANALYSIS---------------=I5/
    3 50H0 NUMBER OF PRESSURE CARDS FOR THE ANALYSIS--------=I5/
    4 50H0 NUMBER OF APPROXIMATIONS FOR STRESS CALCULATION=I5/
    6 50H0 NUMBER OF ANALYSES AT THIS STAGE OF CONSTR.------=I5/
    7 50H0 TIME OF LAYING THE TOP LIFT----------------------=F10.3/
    8 50H0 TIME OF LAYING THE NEXT LIFT---------------------=F10,3)
2009 FORMAT (42H1 NODAL  TEMPERATURES FOR ANALYSIS NUMBER I5,
    1 " STRUCTURE UP TO LIFT ",I5," TIME FROM TAPE =",F8.2,
    2 " DAYS"//" NP.    TEMP",9(13H    NP.    TEMP)/
    3 10(I5,F8.2))
2010 FORMAT (15H0    TEMP./TIME 10X 5HE(C)  9X 6HNW     11X 4HE(T)
    1 10X 5HG/H2  10X 5HALPHA/
    2 (F15.3,4F15.5,E15.5))
2011 FORMAT (17H0MATERIAL NUMBER= I3, 30H. NUMBER OF TEMP./TIME CARDS =
    1I3,24H. NUMBER OF CREEP CARDS=I3, 15H, MASS DENSITY= E12.4)
2012 FORMAT (26H0NODAL POINT CARD ERROR N. I5)
2013 FORMAT (17H0 MATERIAL NUMBER I5//
    1111H COEFFICIENT FUNCTIONS A(T) IN MCHENRYS EQUATION  STRAIN(T) =
    2STRAIN(0)+A1(T)(1-EXP(-M1*T))+A2(T)(1-EXP(-M2*T))//
```

```
     310X, 10HTEMP./TIME 11X, 24HA1,A2 FOR COMPRESS.CREEP 12X, 23HA3,A4
     4FOR TENSILE CREEP// 38X, 2HA1,13X,2HA2,10X,2HA3,13X,2HA4//
     5(10X,F10.3,10X,E10.3,5X,E10.3,10X,E10.3,5X,E10.3))
2014 FORMAT (30H0 INDEXES IN MCHENRYS EQUATION//
     130H    FOR COMPRESSIVE CREEP  M1 =E10.3,6X,4HM2 = E10.3/
     230H    FOR TENSILE CREEP      M3 = E10.3,6X,4HM4 = E10.3)
2017 FORMAT(" ERROR IN DISP/OR FORCE SPEC. AT NODE= ",I5)
2051 FORMAT(" NO. OF STRAIN CAPACITY PTS. = ",I4)
2052 FORMAT(" TIME-DAYS   STRAIN CAP,--UIN./IN,"/2(2X,F10.2))
3000 FORMAT(I5,F5.0,2F10.0)
3007 FORMAT(12F5.0)
3017 FORMAT(12F5.0)
3009 FORMAT(F10.0)
3011 FORMAT(2I5,3F10.2)
3020 FORMAT(2X,I8,F10.0)
3027 FORMAT(//" ERROR ON STRESS FREE TEMP. INPUT AT ELE.,NM= ",I5)
3028 FORMAT(//"      ELEMENT STRESS FREE TEMPERATURES-"//
     110(I5,F8.2))
3040 FORMAT(8X,F8.2)
3041 FORMAT(7(6X,F7.1))
3029 FORMAT(1X,A8)
3030 FORMAT(A8,A8,A1)
4000 FORMAT(I10,F10.0,F10.0)
4001 FORMAT(I5,5I5,3F10.0)
4100 FORMAT(20X,"PERCENT MAXIMUM TENSILE STRAIN WITH RESPECT TO ",
     1"STRAIN CAPACITY",/20X,71(1H*)//25X,"* - STRAIN OF STRAIN",
     2" CAPACITY > OR = 75%",/24X,"** - STRAIN OF STRAIN CAPACITY"
     3" > OR = 90%"//)
5000 STOP
      END
      SUBROUTINE QUAD
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUHOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
       COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
     1CC(4,8),NCREEP(8),SC(30,2,8),NSC
       COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
       COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
       COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
       COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
       COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
     1 F(3,3)
      I=IX(N,1)
      J=IX(N,2)
      K=IX(N,3)
      L=IX(N,4)
      IX(N,5)=IABS(IX(N,5))
```

```
      MTYPE=IX(N,5)
C*****FORM STRESS-STRAIN RELATIONSHIP INCLUDING TIME OR*****
C*****TEMPERATURE DEPENDENCE OF ELASTIC CONSTANTS**************
      DO 15 M=1,4
      MM=IX(N,M)
      RRR(M)=R(MM)
   15 ZZZ(M)=Z(MM)
      TEM=(TEMPE(N)+TOLD(N))/2.
      IF (T1) 50,40,50
   40 DO 103 M=2,30
      IF (E(M,1,MTYPE)-TEM)  103,104,104
  103 CONTINUE
  104 RATIO=0.0
      DEN=E(M,1,MTYPE)-E(M-1,1,MTYPE)
      IF (DEN) 70,71,70
   70 RATIO= (TEM-E(M-1,1,MTYPE))/DEN
      GO TO 71
   50 DO 55 M=2,30
      IF (E(M,1,MTYPE)-TL) 55,60,60
   55 CONTINUE
   60 RATIO=0.
      DEN=E(M,1,MTYPE)-E(M-1,1,MTYPE)
      IF (DEN) 64,71,64
   64 RATIO=(TL-E(M-1,1,MTYPE))/DEN
   71 DO 105 KK=1,5
  105 EE(KK)=E(M-1,KK+1,MTYPE)+RATIO*(E(M,KK+1,MTYPE)-E(M-1,KK+1,MTYPE))
      DO 300 KK=1,2
  300 EES(N,KK)=EE(KK)
      IF(ISC.EQ.0)GO TO 76
      DO 455 MM=2,30
      IF(SC(MM,1,MTYPE)-TL1)455,460,460
  455 CONTINUE
  460 RRAT=0.
      DDEN=SC(MM,1,MTYPE)-SC(MM-1,1,MTYPE)
      IF(DDEN)464,471,464
  464 RRAT=(TL1-SC(MM-1,1,MTYPE))/DDEN
  471 SCAP(N)=SC(MM-1,2,MTYPE)+RRAT*(SC(MM,2,MTYPE)-SC(MM-1,
     12,MTYPE))
   76 IF (MTAG(N)-2) 80,80,81
   80 RATIO=EE(2)
      GO TO 82
   81 RATIO=EE(2)*EE(3)/EE(1)
   82 XX=EE(1)/EE(3)
      YY=1.
      IF (MTAG(N)-1) 83,83,84
   83 XX=YY
   84 IF (MTAG(N)-3) 86,86,85
   85 YY=XX
   86 CONTINUE
      UU=YY-EE(2)*RATIO
      VV=XX-EE(2)*RATIO
      UV=EE(2)*(1.+RATIO)
```

```
      COMM=EE(1)/(VV*UU-UV**2)
      C(1,1)=UU*COMM
      C(1,2)=UV*COMM
      C(1,3)=0.
      C(2,1)=C(1,2)
      C(2,2)=VV*COMM
      C(2,3)=0.
      C(3,1)=0.
      C(3,2)=0.
      C(3,3)=EE(1)/(EE(1)/EE(3)+1.+2.*EE(2))
      THETA=SIG(N,3)/57.296
      SS=SIN(THETA)
      CO=COS(THETA)
      S2=SS*SS
      C2=CO*CO
      SCO=SS*CO
      DO 87 II=1,3
      DO 87 JJ=1,3
   87 F(II,JJ)=C(II,JJ)
      D(1,1)=C2
      D(1,2)=S2
      D(1,3)=SCO
      D(2,1)=S2
      D(2,2)=C2
      D(2,3)=-SCO
      D(3,1)=-2.*SCO
      D(3,2)=-D(3,1)
      D(3,3)=C2-S2
      DO 88 II=1,3
      DO 88 JJ=1,3
      H(II,JJ)=0.0
      DO 88 KK=1,3
   88 H(II,JJ)=H(II,JJ) +C(II,KK)*D(KK,JJ)
      DO 89 II=1,3
      DO 89 JJ=1,3
      C(II,JJ)=0.0
      DO 89 KK=1,3
   89 C(II,JJ)=C(II,JJ)+D(KK,II)*H(KK,JJ)
      DO 100 II=1,10
      P(II)=0.0
      DO 100 JJ=1,10
  100 S(II,JJ)=0.0
      DO 150 II=1,3
      DO 150 JJ=1,10
  150 ST(II,JJ)=0.0
      VOL=0.0
C*****FORM STIFFNESS FOR A CST TRIANGULAR ELEMENT***************
      VOL=0.0
      IF(IX(N,3).NE.IX(N,4))GO TO 700
      CALL STFTRI(1,2,3)
      XC=(R(I)+R(J)+R(K))/3.
      YC=(Z(I)+Z(J)+Z(K))/3.
```

```
C*****FORM STIFFNESS FOR A CST QUADRILATERAL ELEMENT**********
      GO TO 701
  700 XC=(R(I)+R(J)+R(K)+R(L))/4.
      YC=(Z(I)+Z(J)+Z(K)+Z(L))/4.
      RRR(5)=XC
      ZZZ(5)=YC
      CALL STFTRI(4,1,5)
      CALL STFTRI(1,2,5)
      CALL STFTRI(2,3,5)
      CALL STFTRI(3,4,5)
C*****CALCULATE UNBALANCED LOADS DUE TO TEMPERATURE CHANGE****
C*****AND STRESS RELAXATION***********************************
  701 TEMP=(TEMPE(N)-TOLD(N))*EE(5)
      IF(TIM) 170,160,170
  160 TEMP=0.
  170 CONTINUE
      DSIG(1)=SIG(N,1)*C2+SIG(N,2)*S2
      DSIG(2)=SIG(N,1)*S2+SIG(N,2)*C2
      DSIG(3)=(SIG(N,1)-SIG(N,2))*SCO
      DO 190 JJ=1,3
  190 DSIG(JJ)=-DSIG(JJ)+(C(JJ,1)+C(JJ,2))*TEMP
      DO 200 II=1,10
      DO 200 JJ=1,3
  200 P(II)=P(II)+DSIG(JJ)*ST(JJ,II)*VOL
C*****ADD SHEAR STIFFNESS OF FOUNDATION***********************
      IF(IX(N,3).EQ.IX(N,4))GO TO 510
      COMM=VOL*EE(4)
      S(9,9)=S(9,9)+COMM
      S(10,10)=S(10,10)+COMM
C*****ELIMINATE CENTER POINT**********************************
      DO 500 K=1,2
      IH=10-K
      ID=IH+1
      DO 500 I=1,IH
      S(ID,I)=S(ID,I)/S(ID,ID)
      P(I)=P(I)-P(ID)*S(I,ID)/S(ID,ID)
      DO 500 J=1,IH
  500 S(J,I)=S(J,I)-S(J,ID)*S(ID,I)
C*****CALCULATE LOADS DUE TO GRAVITY**************************
  510 CONTINUE
      IF(N-NUMOL) 580,580,540
  540 IF(NNAL.GT.1)GO TO 580
      IF(NNAL.EQ.1.AND.NFLAG.GT.2)GO TO 580
  550 IMUL=4
      IF(IX(N,3).EQ.IX(N,4))IMUL=3
      AMUL=IMUL
      DO 560 I=1,IMUL
  560 P(2*I)=P(2*I)-RO(MTYPE)*VOL/AMUL
  580 CONTINUE
  130 RETURN
      END
      SUBROUTINE ONED
```

```
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
       COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
     1CC(4,8),NCREEP(8),SC(30,2,8),NSC
       COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
       COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
       COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
       COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
       COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
     1 F(3,3)
      DO 100 I=1,8
      P(I)=0.0
      DO 100 J=1,8
  100 S(I,J)=0.0
      MTYPE=IX(N,5)
      I=IX(N,1)
      J=IX(N,2)
      DX=R(J)-R(I)
      DY=Z(J)-Z(I)
      XL=SQRT(DX**2+DY**2)
      COSA=DX/XL
      SINA=DY/XL
      COMM=E(1,2,MTYPE)*E(1,5,MTYPE)/XL
      S(1,1)=COSA*COSA*COMM
      S(1,2)=COSA*SINA*COMM
      S(1,3)=-S(1,1)
      S(1,4)=-S(1,2)
      S(2,1)=S(1,2)
      S(2,2)=SINA*SINA*COMM
      S(2,3)=-S(1,2)
      S(2,4)=-S(2,2)
      S(3,1)=S(1,3)
      S(3,2)=S(2,3)
      S(3,3)=S(1,1)
      S(3,4)=S(1,2)
      S(4,1)=S(1,4)
      S(4,2)=S(2,4)
      S(4,3)=S(3,4)
      S(4,4)=S(2,2)
      EP=SIG(N,1)/E(1,2,MTYPE)
      DX=DX*EP
      DY=DY*EP
      P(1)=S(1,1)*DX+S(1,2)*DY
      P(2)=S(2,1)*DX+S(2,2)*DY
      P(3)=-P(1)
      P(4)=-P(2)
```

AD-A069 376 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/13
VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTE--ETC(U)
MAR 79 T C LIU, R L CAMPBELL, A A BOMBICH

UNCLASSIFIED WES-MP-SL-79-7 NL

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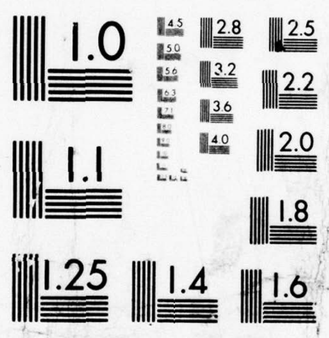

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
      RETURN
      END
      SUBROUTINE STFTRI(II,JJ,KK)
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
C     STIFFNESS MATRIX (S) AND TRANSFORMATION MATRIX (B) FOR CST ELEMENT
C     ARGUMENTS (1,2,3) FOR TRIANGLE
C      (4,1,5),(1,2,5),(2,3,5)AND(3,4,5) FOR QUADRILATERAL
C
      COMMON NUMNP,NUMEL,NUMPC,NN,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
       COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
       COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
       COMMON/LS4ARG/ IN,JN,KN,S(10,10),C(3,3),DUM(18),P(10),LM(4),
     1F1(3,3)
      DIMENSION RR(4),ZZ(4),D(3,6),B(3,10),ANGLE(4),F(3,10)
C
C       1. INITIALIZATION
C
      LM(1)=II
      LM(2)=JJ
      LM(3)=KK
C
      RR(1)=RRR(II)
      RR(2)=RRR(JJ)
      RR(3)=RRR(KK)
      ZZ(1)=ZZZ(II)
      ZZ(2)=ZZZ(JJ)
      ZZ(3)=ZZZ(KK)
C
      DO 30 I=1,3
      DO 20 J=1,10
      F(I,J) = 0.0
   20 B(I,J) = 0.0
      DO 30 J=1,6
   30 D(I,J) = 0.0
C
C     2. AREA  OF TRIANGLE
C
      COMM=RR(2)*(ZZ(3)-ZZ(1))+RR(1)*(ZZ(2)-ZZ(3))+RR(3)*(ZZ(1)-ZZ(2))
      XI = COMM/2.0
      VOL=VOL+XI
C
C     3. FORM COEFFICIENT-DISPLACEMENT MATRIX (B)
C
      D(1,1)=(ZZ(2)-ZZ(3))/COMM
      D(1,3)=(ZZ(3)-ZZ(1))/COMM
      D(1,5)=(ZZ(1)-ZZ(2))/COMM
```

```
      D(2,2)=(RR(3)-RR(2))/COMM
      D(2,4)=(RR(1)-RR(3))/COMM
      D(2,6)=(RR(2)-RR(1))/COMM
      D(3,1)=D(2,2)
      D(3,2)=D(1,1)
      D(3,3)=D(2,4)
      D(3,4)=D(1,3)
      D(3,5)=D(2,6)
      D(3,6)=D(1,5)
C
C     FORM  (B)
C
      DO 50 I=1,3
      DO 50 J=1,3
      K = 2*LM(J)
      L = 2*J
      B(I,K-1)=D(I,L-1)
   50 B(I,K)=  D(I,L)
C
C     ROTATE UNKNOWNS IF REQUIRED
C
      DO 118 M=1,4
      MM=IX(NN,M)
  118 ANGLE(M)=CODE(MM)/57.2958
      LL=2
      IF(IX(NN,3).EQ.IX(NN,4)) LL=3
      DO 125 J=1,LL
      I=LM(J)
      IF(ANGLE(I) .GE. 0.0) GO TO 125
      SINA=SIN(ANGLE(I))
      COSA=COS(ANGLE(I))
      IJ = 2*I
      DO 124 K=1,3
      TEM = B(K,IJ-1)
      B(K,IJ-1)=TEM*COSA+B(K,IJ)*SINA
  124 B(K,IJ) =-TEM*SINA+B(K,IJ)*COSA
  125 CONTINUE
C
C     4. FORM ELEMENT STIFFNESS MATRIX  (B)T*(C)*(B)
C
      DO 130 J=1,10
      DO 130 K=1,3
      IF(B(K,J).EQ. 0.0) GO TO  130
      DO 129 I=1,3
  129 F(I,J)=F(I,J)+C(I,K)*B(K,J)*XI
  130 CONTINUE
C
      DO 140 I=1,10
      DO 140 K=1,3
      IF(B(K,I).EQ.0.0) GO TO  140
      DO 139 J=1,10
  139 S(I,J)=S(I,J)+B(K,I)*F(K,J)
```

```
  140 CONTINUE
C
C      5. TRANSFER OR ACCUMULATE (B) IN (ST) MATRIX
C
      DO 200 I=1,3
      DO 200 J=1,10
  200 ST(I,J)=ST(I,J)+B(I,J)
C
C        CHECK FOR LAST CALL FOR QUADRILATERAL
C
      IF(II.EQ.3) GO TO  250
      RETURN
  250 DO 260 I=1,3
      DO 260 J=1,10
  260 ST(I,J) = ST(I,J)/4.0
C
      RETURN
C
      END
      SUBROUTINE STIFF
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
        COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
     1CC(4,8),NCREEP(8),SC(30,2,8),NSC
        COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
        COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
        COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
        COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
        COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
     1 F(3,3)
C*****INITIALIZATION*****************************************
      REWIND 2
      NB=30
      ND=2*NB
      ND2=2*ND
      STOP=0.0
      NUMBLK=0
      DO 50 N=1,ND2
      B(N)=0.0
      DO 50 M=1,ND
   50 A(N,M)=0.0
C*****FORM STIFNESS MATRIX IN BLOCKS*************************
   60 NUMBLK=NUMBLK+1
      NH=NB*(NUMBLK+1)
      NM=NH-NB
      NL=NM-NB+1
```

```
      KSHIFT=2*NL-2
      N1=1
      DO 220 M=1,LAY
      TL=TIM-TIMLA(M)
      TLI=TIME-TIMLA(M)
      N2=NUME(M)
      DO 210 N=N1,N2
      IF (IX(N,5)) 210,210,65
   65 DO 80 I=1,4
      IF (IX(N,I)-NL) 80,70,70
   70 IF (IX(N,I)-NM) 90,90,80
   80 CONTINUE
      GO TO 210
   90 IF (IX(N,3)-IX(N,2)) 92,91,92
   91 CALL ONED
      GO TO 165
   92 CALL QUAD
      IF (VOL) 164,164,165
  164 WRITE (6,2003) N
C*****ADD ELEMENT STIFFNESS TO TOTAL STIFFNESS************************
  165 IX(N,5)=-IX(N,5)
      DO 166 I=1,4
  166 LM(I)=2*IX(N,I)-2
      DO 200 I=1,4
      DO 200 K=1,2
      II=LM(I)+K-KSHIFT
      KK=2*I-2+K
      B(II)=B(II)+P(KK)
      DO 200 J=1,4
      DO 200 L=1,2
      JJ=LM(J)+L-II+1-KSHIFT
      LL=2*J-2+L
      IF(JJ) 200,200,175
  175 IF(ND-JJ) 180,195,195
  180 WRITE (6,2004) N
      STOP=1.0
      GO TO 210
  195 A(II,JJ)=A(II,JJ)+S(KK,LL)
  200 CONTINUE
  210 CONTINUE
      N1=N2+1
      IF(N1-NUMEL) 220,220,225
  220 CONTINUE
C*****ADD CONCENTRATED FORCES WITHIN BLOCK*****************************
  225 DO 255 N=NL,NM
      K=2*N-KSHIFT
      B(K)=B(K)+UZ(N)
      B(K-1)=B(K-1)+UR(N)
      IF (NCOUNT-NP) 255,250,250
  250 IF (N-NUMN) 252,252,255
  252 UZ(N)=0.
      UR(N)=0.
```

```
  255 CONTINUE
C*****BOUNDARY CONDITIONS*****************************************
C********1.PRESSURE B. C.
      IF (NUMPC) 260,310,260
  260 DO 300 L=1,NUMPC
      I=IBC(L)
      J=JBC(L)
      PP=PR(L)/2.
      DZ=(Z(I)-Z(J))*PP
      DR=(R(J)-R(I))*PP
  264 II=2*I-KSHIFT
      JJ=2*J-KSHIFT
      IF (II) 280,280,265
  265 IF (II-ND) 270,270,280
  270 SINA=0.0
      COSA=1.0
      IF (CODE(I)) 271,272,272
  271 SINA=SIN(CODE(I)/57.3)
      COSA=COS(CODE(I)/57.3)
  272 B(II-1)=B(II-1)+(COSA*DZ+SINA*DR)
      B(II)=B(II)-(SINA*DZ-COSA*DR)
  280 IF (JJ) 300,300,285
  285 IF (JJ-ND) 290,290,300
  290 SINA=0.0
      COSA=1.0
      IF (CODE(J)) 291,292,292
  291 SINA=SIN(CODE(J)/57.3)
      COSA=COS(CODE(J)/57.3)
  292 B(JJ-1)=B(JJ-1)+(COSA*DZ+SINA*DR)
      B(JJ)=B(JJ)-(SINA*DZ-COSA*DR)
  300 CONTINUE
C********2.DISPLACEMENT B. C.
  310 DO 400 M=NL,NH
      IF (M-NUMN) 315,315,400
  315 U=UR(M)
      N=2*M-1-KSHIFT
      IF (CODE(M)) 390,400,316
  316 IF (CODE(M)-1.) 317,370,317
  317 IF (CODE(M)-2.) 318,390,318
  318 IF (CODE(M)-3.) 390,380,390
  370 CALL MODIFY(A,B,ND2,MBAND,N,U)
      GO TO 400
  380 CALL MODIFY(A,B,ND2,MBAND,N,U)
  390 U=UZ(M)
      N=N+1
      CALL MODIFY(A,B,ND2,MBAND,N,U)
  400 CONTINUE
C*****WRITE BLOCK OF EQUATIONS ON DISK, SHIFT UP LOWER BLOCK**
      WRITE (2) (B(N),(A(N,M),M=1,MBAND),N=1,ND)
      DO 420 N=1,ND
      K=N+ND
      B(N)=B(K)
```

```
      B(K)=0.0
      DO 420 M=1,ND
      A(N,M)=A(K,M)
  420 A(K,M)=0.0
C*****CHECK FOR LOWER BLOCK*****************************************
      IF (NM-NUMN)  60,480,480
  480 CONTINUE
      IF(STOP) 490,500,490
  490 CALL EXIT
  500 RETURN
 2003 FORMAT (26H0NEGATIVE AREA ELEMENT NO, I4)
 2004 FORMAT (29H0BAND WIDTH EXCEEDS ALLOWABLE I4)
      END
      SUBROUTINE MODIFY(A,B,NEQ,MBAND,N,U)
      DIMENSION A(120,60),B(120)
      DO 250 M=2,MBAND
      K=N-M+1
      IF(K) 235,235,230
  230 B(K)=B(K)-A(K,M)*U
      A(K,M)=0.0
  235 K=N+M-1
      IF(NEQ-K) 250,240,240
  240 B(K)=B(K)-A(N,M)*U
      A(N,M)=0.0
  250 CONTINUE
      A(N,1)=1.0
      B(N)=U
      RETURN
      END
      SUBROUTINE BANSOL
       COMMON /BANARG/ MM,NUMBLK,B(120),A(120,60)
      NN=60
      NL=NN+1
      NH=NN+NN
      REWIND 1
      REWIND 2
      NB=0
      GO TO 150
C*****REDUCE EQUATIONS BY BLOCKS*************************************
C********1. SHIFT BLOCK OF EQUATIONS
  100 NB=NB+1
      DO 125 N=1,NN
      NM=NN+N
      B(N)=B(NM)
      B(NM)=0.0
      DO 125 M=1,MM
      A(N,M)=A(NM,M)
  125 A(NM,M)=0.0
C********2. READ NEXT BLOCK OF EQUATICNS INTO CORE
      IF (NUMBLK-NB) 150,200,150
  150 READ (2) (B(N),(A(N,M),M=1,MM),N=NL,NH)
      IF (NB) 200,100,200
```

```
C********3. REDUCE BLOCK OF EQUATIONS
  200 DO 300 N=1,NN
      IF (A(N,1)) 225,300,225
  225 B(N)=B(N)/A(N,1)
      DO 275 L=2,MM
      IF (A(N,L)) 230,275,230
  230 C=A(N,L)/A(N,1)
      I=N+L-1
      J=0
      DO 250 K=L,MM
      J=J+1
  250 A(I,J)=A(I,J)-C*A(N,K)
      B(I)=B(I)-A(N,L)*B(N)
      A(N,L)=C
  275 CONTINUE
  300 CONTINUE
C********4. WRITE BLOCK OF EQUATIONS ON DISK 2***************
      IF (NUMBLK-NB) 375,400,375
  375 WRITE (1) (B(N),(A(N,M),M=2,MM),N=1,NN)
      GO TO 100
C*****BACK SUBSTITUTION**************************************
  400 DO 450 M=1,NN
      N=NN+1-M
      DO 425 K=2,MM
      L=N+K-1
  425 B(N)=B(N)-A(N,K)*B(L)
      NM=N+NN
      B(NM)=B(N)
  450 A(NM,NB)=B(N)
      NB=NB-1
      IF (NB) 475,500,475
  475 BACKSPACE 1
      READ (1) (B(N),(A(N,M),M=2,MM),N=1,NN)
      BACKSPACE 1
      GO TO 400
C*****ORDER UNKNOWNS IN B ARRAY*******************************
  500 K=0
      DO 600 NB=1,NUMBLK
      DO 600 N=1,NN
      NM=N+NN
      K=K+1
  600 B(K)=A(NM,NB)
      RETURN
      END
      SUBROUTINE CREEP
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIP,
     2TTT(15),NUMOL,TIME,NMAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
       COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
```

```
      1CC(4,8),NCREEP(8),SC(30,2,8),NSC
       COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),YOLD(MXE),
      1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCQ(4),CCC(4)
      2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
       COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
       COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)
       COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
       COMMON /LS4ARG/ I,J,K,S(10,10),C(5,3),D(3,3),H(3,3),P(10),LM(4),
      1F(3,3)
       CHARACTER DASH*6,OVER*6,STB*1(2)
       MPRINT=0
       N1=1
       IC=1
       DO 600 M=1,LAY
       N2=NUME(M)
       DO 550 MM=N1,N2
       N=MM
       TL=TIM-TIMLA(M)
       TL1=TIME-TIMLA(M)
C*****EVALUATE ELEMENT STRESSES**********************************
       CALL STRESS
       IF (IX(N,2)-IX(N,3)) 255,104,255
  255 MTAG(N)=1
       IF (DSIG(4)) 104,104,259
  259 IF (DSIG(4)+DSIG(5)) 260,260,261
  260 MTAG(N)=2
       GO TO 104
  261 MTAG(N)=3
  265 IF (DSIG(5)) 104,104,266
  266 MTAG(N)=4
  104 IF(NFLAG.GT.1)GO TO 106
       IF (MPRINT) 106,105,106
  105 IF(ISC.EQ.0)GO TO 750
       WRITE(6,2005)DT
       WRITE(6,2000)LAY,NANAL,TIME,NCOUNT
       WRITE(7,2007)LAY,NANAL,TIME,DT
       GO TO 760
  750 WRITE(6,2005)DT
       WRITE(6,2002)LAY,NANAL,TIME,NCOUNT
  760 WRITE(3)LAY,NANAL,TIME,NCOUNT
       MPRINT=50
  106 CONTINUE
C*****CALCULATE ELEMENT STRAINS**********************************
       EPS(1)=(1./EES(N,1))*((1.-EES(N,2)**2)*DSIG(1)-EES(N,2)
      1*(1.+EES(N,2))*DSIG(2))
       EPS(2)=(1./EES(N,1))*((1.-EES(N,2)**2)*DSIG(2)-EES(N,2)
      1*(1.+EES(N,2))*DSIG(1))
       EPS(3)=(2.*(1+EES(N,2))*DSIG(3))/EES(N,1)
       EPST1=(EPS(1)+EPS(2))/2.
       EPST2=.5*(SQRT(((EPS(1)-EPS(2))**2)+EPS(3)**2))
       EPS(4)=EPST1+EPST2
       EPS(5)=EPST1-EPST2
```

```
      SDIFF=EPS(1)-EPS(2)
      EPS(6)=ATAN2(EPS(3),SDIFF)/2.
      EPS(6)=57.296*EPS(6)
      DO 700 IIE=1,5
  700 EPS(IIE)=EPS(IIE)*1000000.
      EABREV=EES(N,1)/1000000.
      IF(NFLAG.GT.1)GO TO 751
      DO 759 JL=1,2
      IF(EPS(JL))755,755,756
  755 ETR(JL)=1H
      GO TO 759
  756 ETR(JL)=1H*
  759 CONTINUE
C*****COMPARE STRAIN TO STRAIN CAPACITY IF APPLICABLE*******
      IF(ISC.EQ.0)GO TO 305
      IF(EPS(4)-0.)706,706,705
  705 NSX=(EPS(4)/SCAP(N))*100.+0.5
      IF(NSX.GE.1000)GO TO 720
      IF(NSX.LT.75)GO TO 725
      IF(NSX.GE.90)GO TO 726
      ENCODE(NX7(IC),729)" ",NSX,"* "
  729 FORMAT(A1,I3,A2)
      GO TO 709
  726 ENCODE(NX7(IC),729)" ",NSX,"**"
      GO TO 709
  725 ENCODE(NX7(IC),729)" ",NSX,"  "
      GO TO 709
  720 NX7(IC)=OVER
      GO TO 709
  706 NX7(IC)=DASH
      NSX=0
      NY7(IC)="  --- "
      GO TO 740
  709 ENCODE(NY7(IC),736)" ",EPS(6)
  736 FORMAT(A1,F5.1)
  740 NE7(IC)=N
      IF(IC.EQ.7.OR.N.EQ.NUME(LAY))GO TO 730
      IC=IC+1
      GO TO 761
  730 WRITE(7,742)(NE7(I),NX7(I),NY7(I),I=1,IC)
  742 FORMAT(7(1X,I5,2(A6)))
      IC=1
  761 WRITE(6,2001)N,XC,YC,(DSIG(I),I=1,6),EPS(1),ETR(1),EPS(2),
     1ETR(2),(EPS(I),I=3,6),EABREV,EES(N,2),SCAP(N)
      WRITE(3)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6),
     1(EES(N,I),I=1,2),SCAP(N)
      GO TO 751
  305 WRITE(6,2003)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6),EABREV
     1,EES(N,2)
      WRITE(3)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6)
     1,(EES(N,I),I=1,2)
C*****RELAX STRESS FOR CREEP WITH CONSTANT STRAIN-FOR NCREEP>0
```

```
C*******************************************************************
  751 IF(NCOUNT-NP)550,50,50
   50 IF(IX(N,2)-IX(N,3))55,550,55
C*****INTERPOLATION OF CREEP CONSTANTS******************************
   55 I=IX(N,1)
      J=IX(N,2)
      K=IX(N,3)
      L=IX(N,4)
      IX(N,5)=IABS(IX(N,5))
      MTYPE=IX(N,5)
      TOLD(N)=TEMPE(N)
      IF (NCREEP(MTYPE)) 250,250,60
   60 NCR=NCREEP(MTYPE)
      IF(T1) 120,110,120
  110 TL=TEMPE(N)
  120 DO 140 NN=2,NCR
      IF (TL-TTT(NN)) 125,150,140
  125 TM=TTT(NN)-TTT(NN-1)
      DIFF= TL-TTT(NN-1)
      DO 130 KK=1,4
  130 CCO(KK)=CIC(NN-1,KK,MTYPE)+DIFF*(CIC(NN,KK,MTYPE)-CIC(NN-1,KK,MTYP
     1E))/TM
      GO TO 160
  140 CONTINUE
  150 DO 155 KK=1,4
  155 CCO(KK)=CIC(NN,KK,MTYPE)
  160 DO 165 KK=1,4
  165 CCC(KK)=CC(KK,MTYPE)
C*****SELECT APPROPRIATE CONSTANTS**********************************
      IF (DSIG(4)) 170,170,175
  170 KK=1
      GO TO 180
  175 KK=3
  180 CCO1=CCO(KK)
      CCO2=CCO(KK+1)
      CCO3=CCO1
      CCO4=CCO2
      CCC1=CCC(KK)
      CCC2=CCC(KK+1)
      CCC3=CCC1
      CCC4=CCC2
      IF (DSIG(5)) 185,185,190
  185 CCO3=CCO(1)
      CCO4=CCO(2)
      CCC3=CCC(1)
      CCC4=CCC(2)
  190 CONTINUE
C*****MODIFICATION OF STRESSES TO ALLOW FOR CREEP RELAXATION**
C*****OF STRESS AT CONSTANT STRAIN ON THE APPLICATION OF A****
C*****TIME INCREMENT************************************************
      THETA=(DSIG(6)-SIG(N,3))/57.296
      CO=COS(THETA)
```

```
      SS=SIN(THETA)
      C2=CO*CO
      S2=SS*SS
      SIG1=C2*(SIG(N,4)+SIG(N,1))+S2*(SIG(N,5)+SIG(N,2))
      SIG2=S2*(SIG(N,4)+SIG(N,1))+C2*(SIG(N,5)+SIG(N,2))
      IF (T1) 192,191,192
  191 DE11(N)=DSIG(4)*CCC2*CCO2
      DE12(N)=DSIG(4)*CCC1*CCO1
      DE21(N)=DSIG(5)*CCC4*CCO4
      DE22(N)=DSIG(5)*CCC3*CCO3
      GO TO 195
  192 DET11= C2*DE11(N)+S2*DE21(N)
      DET12= C2*DE12(N)+S2*DE22(N)
      DET21= S2*DE11(N)+C2*DE21(N)
      DET22= S2*DE12(N)+C2*DE22(N)
      DE11(N)= DET11+(DSIG(4)-SIG1)*CCC2*CCO2
      DE12(N)= DET12+(DSIG(4)-SIG1)*CCC1*CCO1
      DE21(N)= DET21+(DSIG(5)-SIG2)*CCC4*CCO4
      DE22(N)= DET22+(DSIG(5)-SIG2)*CCC3*CCO3
  195 CONTINUE
      SIG(N,1)=0.
      SIG(N,2)=0.
      TR=0.
  220 TR=TR+DTT
      DELTA1=(DE11(N)+DE12(N))*DTT
      DELTA2=(DE21(N)+DE22(N))*DTT
      SIG1=DELTA1*F(1,1)
      SIG2=DELTA2*F(2,2)
      SIG(N,1)=SIG(N,1)-SIG1
      SIG(N,2)=SIG(N,2)-SIG2
C*****CALCULATION OF CREEP RATES FOR THE NEXT TIME INTERVAL***
      DE11(N)= DE11(N)*(1.-DTT*CCC2)
      DE12(N)= DE12(N)*(1.-DTT*CCC1)
      DE21(N)= DE21(N)*(1.-DTT*CCC4)
      DE22(N)=DE22(N)*(1.-DTT*CCC3)
      DE11(N)=DE11(N)-SIG1*CCC2*CCO2
      DE12(N)=DE12(N)-SIG1*CCC1*CCO1
      DE21(N)=DE21(N)-SIG2*CCC4*CCO4
      DE22(N)=DE22(N)-SIG2*CCC3*CCO3
C     IF(TR-DT)220,250,250
  250 SIG(N,3)=DSIG(6)
      SIG(N,4)=DSIG(4)
      SIG(N,5)=DSIG(5)
  550 CONTINUE
      N1=N2+1
      IF (N1-NUMEL) 600,600,650
  600 CONTINUE
  650 CONTINUE
      RETURN
 2005 FORMAT(1H1," PRESENT TIME INCREMENT--DT-",F7.2," DAYS")
 2000 FORMAT(" NO. OF LIFTS/OR TIME SPANS-",I5/" ANALYSIS ",
     1"CYCLE NO.",9(1H-),I5,20X,"*KEY FOR CHARACTER POSITION"
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     2," FOLLOWING EPI-X & EPI-Y BELOW**/"STRESS AND STRAINS",
     3" AFTER----",F7.2," DAYS",14X,"* = TENSILE STRAIN"/
     4" APPROXIMATION NO."*10(1H-),I5,20X,"BLANK = COMPR. STRAIN",
     5//" ELEM",
     6" CENTROID-IN.  ",18(1H-),"PSI",18(1H-),"  ANGLE ",13(1H-),
     7"MICROSTRAINS",14(1H-),"  ANGLE  E(C)  POIS S.CP*"/
     8"  NO. X-ORD  Y-ORD     SIG-X   SIG-Y  SIG-XY   SIG-1   SIG",
     9"-2  WRT+X  EPI-X   EPI-Y    EPI-XY   EPI-1   EPI-2  WRT+X",
     1" *10**6 RTIO U-IN."//)
2002 FORMAT(" NO. OF LIFTS/OR TIME SPANS- ",I5/" ANALYSIS ",
     1"CYCLE NO.",9(1H-),I5/" STRESS AND STRAIN AFTER---",F7.2,
     2" DAYS"/" APPROXIMATION NO."*10(1H-),I5//" ELEM ",
     3"CENTROID-IN.  ",18(1H-),"PSI",18(1H-),"  ANGLE ",13(1H-),
     4"MICROSTRAINS",14(1H-),"  ANGLE  E(C)  POISS"/"  NO. ",
     5"X-ORD  Y-ORD     SIG-X    SIG-Y  SIG-XY    SIG-1    SIG-2  ",
     6"WRT+X   EPI-X    EPI-Y  EPI-XY   EPI-1   EPI-2  WRT+X ",
     7"*10**6 RATIO"//)
2003 FORMAT(I4,1X,2F7.1,5F8.1,F7.2,5F8.1,F7.2,F7.3,F5.2)
2001 FORMAT(I4,1X,2F7.1,5F8.1,F7.2,F8.1,2(A1,F7.1),2F8.1,
     1F7.2,F7.3,F5.2,F7.1)
2007 FORMAT(///" LIFT NO.          ",I8/" LIFT ANAL NO.---",I8/
     1" TIME(DAYS)------",F10.2/" TIME INCR(DAYS)-",F10.2
     2,//7("  ELEM XE(1) ANGLE")//)
      END
      SUBROUTINE STRESS
      PARAMETER MXN=576,MXE=475
      CHARACTER NX7*6(7),NY7*6(7)
      COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
     1,NDT,NCOUNT,TI,DT,DTT,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
     2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANALT,TLAST
     3,RRR(5),ZZZ(5),NFLAG,TL1
       COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
     1CC(4,8),NCREEP(8),SC(30,2,8),NSC
       COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
     1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
     2,EES(MXE,2),EPS(6),SEAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
       COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
       COMMON /ORDARG/ R(MXN),Z(MXN),LR(MXN),UZ(MXN),CODE(MXN),T(MXN)
       COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
       COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
     1 F(3,3)
C*****COMPUTE ELEMENT STRESSES*************************************
      DO 50 I=1,6
   50 DSIG(I)=0.0
      IF (IX(N,3)-IX(N,2)) 90,80,90
C*****FOR ONE-D ELEMENT********************************************
   80 I=IX(N,1)
      J=IX(N,2)
      DX=R(J)-R(I)
      DY=Z(J)-Z(I)
      XL=SQRT(DX**2+DY**2)
      DU=B(2*J-1)-B(2*I-1)
```

```
      DV=B(2*J)-B(2*I)
      DL=DV*DY/XL +DU*DX/XL
      DSIG(1)=DL*E(1,2,MTYPE)/XL+SIG(N,1)+SIG(N,4)
      IF (NCOUNT-NP) 85,84,84
   84 SIG(N,4)=DSIG(1)
      SIG(N,1)=0.
   85 XC=0.0
      YC=0.0
      GO TO 320
C*****FOR TWO-D ELEMENT*****************************************
   90 CALL QUAD
      DO 120 I=1,4
      II=2*I
      JJ=2*IX(N,I)
      P(II-1)=B(JJ-1)
  120 P(II)=B(JJ)
      DO 150 I=9,10
      P(I)=0.0
      KK=I-1
      DO 150 K=1,KK
  150 P(I)=P(I)-S(I,K)*P(K)
      D(1,1)=0.
      D(2,1)=0.
      D(3,1)=0.0
      DO 170 I=1,3
      DO 170 K=1,10
  170 D(I,1)=D(I,1)+ST(I,K)*P(K)
      THETA= SIG(N,3)/57.296
      CO=COS(THETA)
      SS=SIN(THETA)
      C2=CO*CO
      S2=SS*SS
      SCO=SS*CO
      DSIG(1)= SIG(N,4)*C2+SIG(N,5)*S2-DSIG(1)
      DSIG(2)= SIG(N,4)*S2+SIG(N,5)*C2-DSIG(2)
      DSIG(3)=(SIG(N,4)-SIG(N,5))*SCO-DSIG(3)
      DO 180 I=1,3
      DO 180 K=1,3
  180 DSIG(I)= DSIG(I)+ C(I,K)*D(K,1)
C*****OUTPUT STRESSES*******************************************
C*****CALCULATE PRINCIPAL STRESSES******************************
      AA=(DSIG(1)+DSIG(2))/2.
      BB= (DSIG(1)-DSIG(2))/2.
      CR= SQRT(BB**2+DSIG(3)**2)
      DSIG(4)=AA+CR
      DSIG(5)=AA-CR
      IF ((BB.EQ.0.0).AND.(DSIG(3).EQ.0.0)) GO TO 320
      DSIG(6)=ATAN2(DSIG(3),BB)/2.
      DSIG(6)=57.296*DSIG(6)
  320 RETURN
      END
$       EXECUTE
```

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3118T 01  08-11-78   15.617

$       LIMITS   100,52K,,20K                                 00012320
$       FILE     01,X1R,10L                                   00012330
$       FILE     02,X2R,10L                                   00012340
$       FILE     07,D1S,10L                                   00012350
$       TAPE9    04,A2D,,8517,,                               00012360
$       TAPE9    03,A1D,,,,DWORSHAK-STRESS                    00012380
$       MSG2     SAVE 03,CAMPBELL,B0CC46,DWORSHAK-STRESS      00012390
$       DATA     20                                           00012400
$       SELECTA  INPUT1                                       00012410
$       BREAK                                                 00012420
$       CONVER                                                00012430
$       LIMITS   ,,,8K                                        00012440
$       SYSOUT   OT                                           00012450
$       FILE     IN,D1R                                       00012460
$       ENDJOB                                                00012470
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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Liu, Tony C
Verification of temperature and thermal stress analysis computer programs for mass concrete structures / by Tony C. Liu, Roy L. Campbell, Anthony A. Bombich. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
47, [59] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; SL-79-7)
Prepared for U. S. Army Engineer District, Walla Walla, Walla Walla, Wash.
References: p. 47.

1. Computer programs. 2. Concrete dams. 3. Concrete structures. 4. Dworshak Dam. 5. Mass concrete. 6. Temperature. 7. Thermal stresses. I. Bombich, Anthony A., joint author. II. Campbell, Roy L., joint author. III. United States. Army. Corps of Engineers. Walla Walla District. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; SL-79-7.
TA7.W34m no.SL-79-7